Report on

# Co-ordination and review of resistivity survey results from the Meager Creek Geothermal Area, 1974 to present.

by

Greg A. Shore
and
Michael G. Schlax

for

B. C. Hydro and Power Authority

April 27, 1982



**PREMIER GEOPHYSICS INC.**

#4 - 11220 VOYAGEUR WAY, RICHMOND, B.C., CANADA V6X 3E1 • (604) 270-6885

TABLE OF CONTENTS

## TABLE OF CONTENTS, cont'd



## LIST OF FIGURES

LIST OF FIGURES, cont'd



APPENDICES



Note: The accompanying volume "Resistivity survey results from the Meager Creek Geothermal Area, 1974 to present" is a part of This report.

# 1.0 SUMMARY AND CONCLUSIONS

## 1.1 General Statement

The electrical resistivity survey method has provided important exploration information and guidance in the program of geothermal exploration at Meager Creek since its introduction in 1974. The method is recognized internationally as one of the most useful tools in the location and delineation of geothermal resources.

The steep, highly dissected terrain of the Meager area provides both advantages and disadvantages in the application of resistivity methods. On the one hand, the glacier-scoured valleys provide good low elevation access for direct measurement of basement rock resistivity and of transported signs of nearby geothermal activity in the form of outflow brine accumulations. On the other hand, having provided for the relatively simple mapping of signs of initial interest, the same terrain provides for extreme difficulty in extending exploration into the higher elevations in search of the a major geothermal system.

The resistivity method has been effective in programs around the world. Its continued effectiveness at Meager Creek and throughout B.C. depends on the continuous testing and reevaluation of results as exploration progresses, so that resistivity survey designs of maximum cost-effectiveness can be consistently applied. At present, the principal challenge is to find a cost-effective method for measuring in the difficult terrain typical of the central Meager Mountain complex.

Since there has been no commercial discovery to date at Meager, any analysis of the cost-effectiveness of methods which have provided interpretatble results to date can be made only on a relative, quite academic level. By continued implementation of conventional exploration methods adapted to local conditions, some measure of appropriate cost-effectiveness control is applied vis-a-vis demonstrated effectiveness in other areas of the world. The fine-tuning of what approach is most useful and effective at Meager Creek can only occur following at least one commercial discovery.

## 1.2 The Basis for Ongoing Analysis

The present report brings the resistivity data from 1974 to 1980 (and part of 1981) together in a standard drafted format with directly comparable measurement units. A summary map showing coverage and the location of anomalous results to date allows independent interpretation of the overall resistivity picture by other workers, and serves as a means of interrelating the individual pseudosection plots of results. Both the catalog of results and the summary map should be updated as new information becomes available, in order that a complete interpretation can be maintained , and an organized recollection of prior work and results can be used to assist planning of new measurements.

## 1.3 Computer-assisted Interpretation

The state of the art in computer-assisted interpretation of resistivity data is in a state of rapid advance, with a number of techniques available for use. One of the most advanced routines, the interactive forward modelling two-dimensional program "IP2D" of the Earth Sciences Laboratory of the University of Utah Research Institute has been most recently used on south reservoir data. The results of this modelling will be substantially tested with the current rotary drill hole (well MC3). A favourable correlation between the modelled results and the temperature and permeability characteristics in this test well should result in a wider program of evaluation and usage of this routine.

One-dimensional inverse and forward modelling routines are available for assisting in the interpretation of Schlumberger soundings and partial soundings; their usefulness in routinely extending the knowledge gained from such measurements should be further investigated. The program presently in development by Dr. Doug Oldenburg of the University of British Columbia may be of most use in handling the irregular data obtained in the Meager terrain. This program is being tested on Meager data at present and should be available by late 1982.

## 2.0 INTRODUCTION

### 2.1 Terms of reference

Premier Geophysics Inc. was retained by B.C. Hydro to review and co-ordinate resistivity survey data obtained in the Meager Creek geothermal area between 1974 and 1980. The work is undertaken under B.C. Hydro purchase order # 142 345, dated January 16, 1981.

### 2.2 Scope of this report

The principal task undertaken has been the redrafting of some resistivity data to make it compatible with the larger body of accumulated data in etrms of units and scale. The format used has been employed in 1981 survey reporting, and these plots have been included as well. The compiled resistivity data from 1974 to 1980 and part of 1981 accompanies this report as a separate volume.

Summary map figure 5.1 includes 1981 resistivity survey results, and marks the location of KRTA alpine resistivity measurements obtained in 1981. The KRTA data are analysed elsewhere, and are noted here to complete the coverage picture for planning purposes.

The major anomaly systems at Meager are reinterpreted to the extent possible with existing data. Areas of interest are identified on figure 5.1 and commented on informally in order to place observations before a readership of other workers in all specialties.

The principal author (Shore) has been involved at Meager since 1975 in designing and operating resistivity surveys. It is his intention in this report to present the objective data listings for others to analyse, and to present a general chronology of the development of the geophysical approach. Complete objectivity under the circumstances is unlikely to be achieved by one so close to the project; however, it is hoped that in this orgainization of complete documentation of the work to date, the accumulated experience from the area can be utilized in assessing and implementing increasingly effective techniques for ongoing exploration.

## 3.0 DISCUSSION OF RESISTIVITY APPROACH

### 3.1 Causes of resistivity anomalies at Meager Creek

Dry or unfractured impermeable rock exhibits very high electrical resistivity characteristics. In the absence of continuous conductors of metallic minerals or graphite, the conductance of electricity through most rocks is dependent upon connected fractures or pore spaces filled with water. Rock resistivity is therefore dependent upon the amount of connected pore space (density of fractures, or inherent permeability of the rock) and upon the resistivity of the water within the pore space.

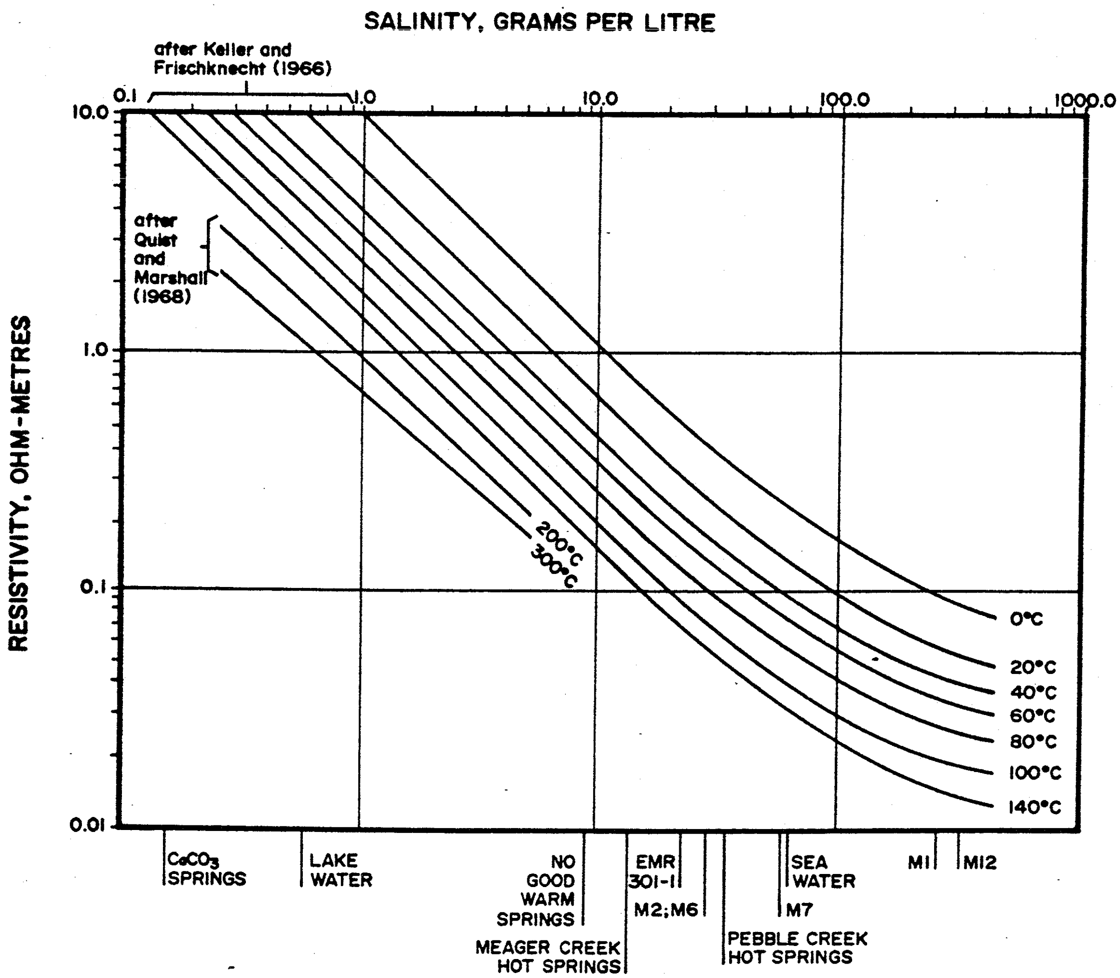



Figure 3.1 Variation of water resistivity with temperature and salinity

Several factors common to geothermal environments contribute to the creation of resistivity anomalies which are relatively simple to detect. The fracturing of otherwise impermeable crystalline rocks by regional stresses, forcible emplacement of volcanics, and by thermal shock provides connected channels for the circulation of water, the chief mechanism for the conducting of electricity in the earth.

Alteration of rocks over a geothermal cell by heat, fluids and gases increases permeability, thereby lowering electrical resistivity. The alteration products, chiefly clays, serve as ion donors to effectively reduce the resistivity of the pore waters further.

Concentration of dissolved salts in a convecting geothermal cell lowers the resistivity of the geothermal waters, increasing the likelihood of detecting and discriminating a low resistivity geothermal signature directly within the cell or in any outflow leakage plume by resistivity survey methods. The effect of salinity on water resistivity is shown in Figure 3.1.

Temperature plays a further role in establishing a readily detectable resistivity signature for geothermal fluids or structures. As shown in Figure 3.1, the greatest temperature effect occurs between 0°C and about 100°C, which is the range of temepratures most likely encountered in shallow (upper kilometre) exploration coverage.

The presence of substantial areas of crystalline basement rocks at surface in B.C. geothermal areas enhances the "visibility" of geothermal anomalies, since these rocks are normally of a high resistivity characteristic (500 to 10,000 ohm-metres) in the absence of geothermal factors. Thus, an anomaly registering 100 ohm-metres in this environment is clearly worthy of investigation, since it may represent .1 ohm-metre geothermal fluids in fractures in 1000 ohm-metre rock.

This advantage of high background:anomaly ratio becomes less reliable in volcanic terranes. Some volcanic units weather rapidly to a highly altered, low resistivity state similar to that which would be expected to result from hydrothermal alteration, in a current, ongoing state or in a long-cooled earlier phase. Geological, petrological and geochemical studies may indicate the nature of the alteration mechanism, but to the initial resistivity survey, it is simply a low resistivity response. The altered tuff unit in the Pylon assemblage is an example; 1978 resistivity measurements of this unit were uniformly low, with a transition to higher resistivities clearly defined at the contact of this unit with basement rocks. The coincidence of the resistivity low with the volcanic unit cannot be dismissed outright; on the other hand, it provides an impediment to interpreting the meaning of any resistivity measurements which sample across the boundaries of these units on a less than systematic scale.

On the north slopes of the complex, rhyodacite flows exhibit resistivities higher than any crystalline basement measurements: up to 14,000 ohm-metres. This does not guarantee reliable interpretation of high ratio anomalies however. Such flow units can (and do) cover prior alluvial deposits, including conductive clay beds, providing an initial appearance of sharply increasing conductivity with depth. Such a situation can occur over an area sufficiently large to constitute a reasonably sized geothermal cell zone; only a measurement program of sufficient vertical resolution can establish whether the conductivity trend continues to depth, as over a geothermal cell, or represents only a conductive basal till. Computer-assisted data interpretation using full Schlumberger soundings (where a one-dimensional layered earth is likely) or using dipole-dipole traverses (where two dimensional complications may be present) can quickly establish which situation may exist.

Anomalous low resistivities will occur directly over a geothermal system at a depth from surface determined by local water table characteristics, local fresh-water hydrology, and by the nature of surface cover, ice, alluvium, or rock structures. Direct detection of a system requires survey methods which are chosen to ensure adequate penetration to sample the system in a way that permits its signature to be discriminated from other area effects.

While a geothermal system may have a surface area of 10 to 30 $km^2$, outflow plumes may involve more or less area in one or more zones of outflow. Outflow waters will follow structural conduits at depth and will ususally eventually be controlled by local drainage basin hydrology, following surface drainage patterns. Outflow plumes and near-surface reservoir leakages provide a useful indicator of nearby geothermal activity, and may provide the most efficient means of preliminary evaluation of an area of interest.

Systematic measurement of valley bottom resistivities has been used at Meager Creek to identify at an early stage the present south reservoir zone, the north anomaly area of interest, and the South Fork anomaly. The valley alluvium appears to act as a concentrator of brine volume, so that a small outflow volume will accumulate in the overburden, presenting a large resistivity anomaly to the resistivity reconnaissance survey.

## 3.2 Resistivity survey methods applied at Meager Creek

The objective of resistivity survey is to map the apparent resistivity of the earth in an area of interest, to assist in the generation of geological models for testing. In the selection of the specific type of electrode layout, there is a large and well-established body of experience, both in the field and in theoretical and in test-modelling programs, on which to base the decision. Exploration requirements (how deep to the target, what is the target characteristic in resistivity, dimension, isotropy, etc.) will dictate a limited range of array types and sizes; local terrain and geologic factors will further limit the choice of method.

Two factors influence the decision on array type in the final analysis: having narrowed the range to several methods which will sample as required, the final factors are often 1) the array's ability to provide unambiguous data under local conditions, or 2) the array's ability to obtain support data which will allow less ambiguous interpretation of probably ambiguous data.

The obvious choice, if it can be established to exist, is the array which provides unambiguous data in the first place, provided the cost-effectiveness is comparable. The selection of array approach is never "final"; effective use of the resistivity tool requires continuous reassessment of array performance and the implementation of whatever modifications are required to obtain the specific information needed. Thus, an area of interest may be identified by a certain reconnaissance array valued for its low cost and rapid coverage, but of limited use in delineating the observed anomaly. A second array more suited to mapping reservoir boundaries may be employed, followed by one which is useful in generating data for modelling of deep structure or perhaps responsive to the anisotropic signature of aligned fissures.

### 3.2.1 Reconnaissance resistivity

Following identification of the Meager Mountain volcanic complex in 1973 as a prime geothermal prospect, a reconnaissance resistivity survey was designed and operated around the northeast, east and south sides of the complex. The array was a dipole-dipole array, (dimensions a=1000 feet, n=1 to 4) as used in a large number of geothermal exploration programs around the world.

The results of this initial survey, and of an extension to this survey undertaken in a few days late in 1978 (Line L) are shown in Figure 3.2. The 1974 data identified the present south reservoir zone, identified the conductive signature of the lower South Fork anomaly, and identified several still untested anomalies in the Lillooet River valley. The 1978 extension of this coverage identified the north anomaly area of interest ( the 1978 test well L1-78D remains the highest temperature well on the north side to date).

All three areas of current exploration interest were thus identified in the initial reconnaissance valley-bottom surveys. At the south reservoir area, the reconnaissance survey may have directly sampled a portion of a reservoir structure; the drilling of this area has not yet established the conditions at depth in the area. In all three cases, however, all or part of the anomaly has been shown to be measuring some geothermal characteristics which indicate the presence of a geothermal system somewhere in the area.

Such reconnaissance surveys are cost-effective, requiring minimal line preparation in most areas, and no line preparation in valleys served by logging or other roads. An advantage is the broad lateral sweep of measurement afforded by the dipole-dipole array, allowing a single-pass evaluation of most valley bottoms and part of their lower slopes, in search of brine saturation.


DIPOLE-DIPOLE ARRAY
DEFINITE RESISTIVITY ANOMALY
POSSIBLE RESISTIVITY ANOMALY

RESULTS OF VALLEY-BOTTOM RECONNAISSANCE RESISTIVITY SURVEYS

Figure 3.2

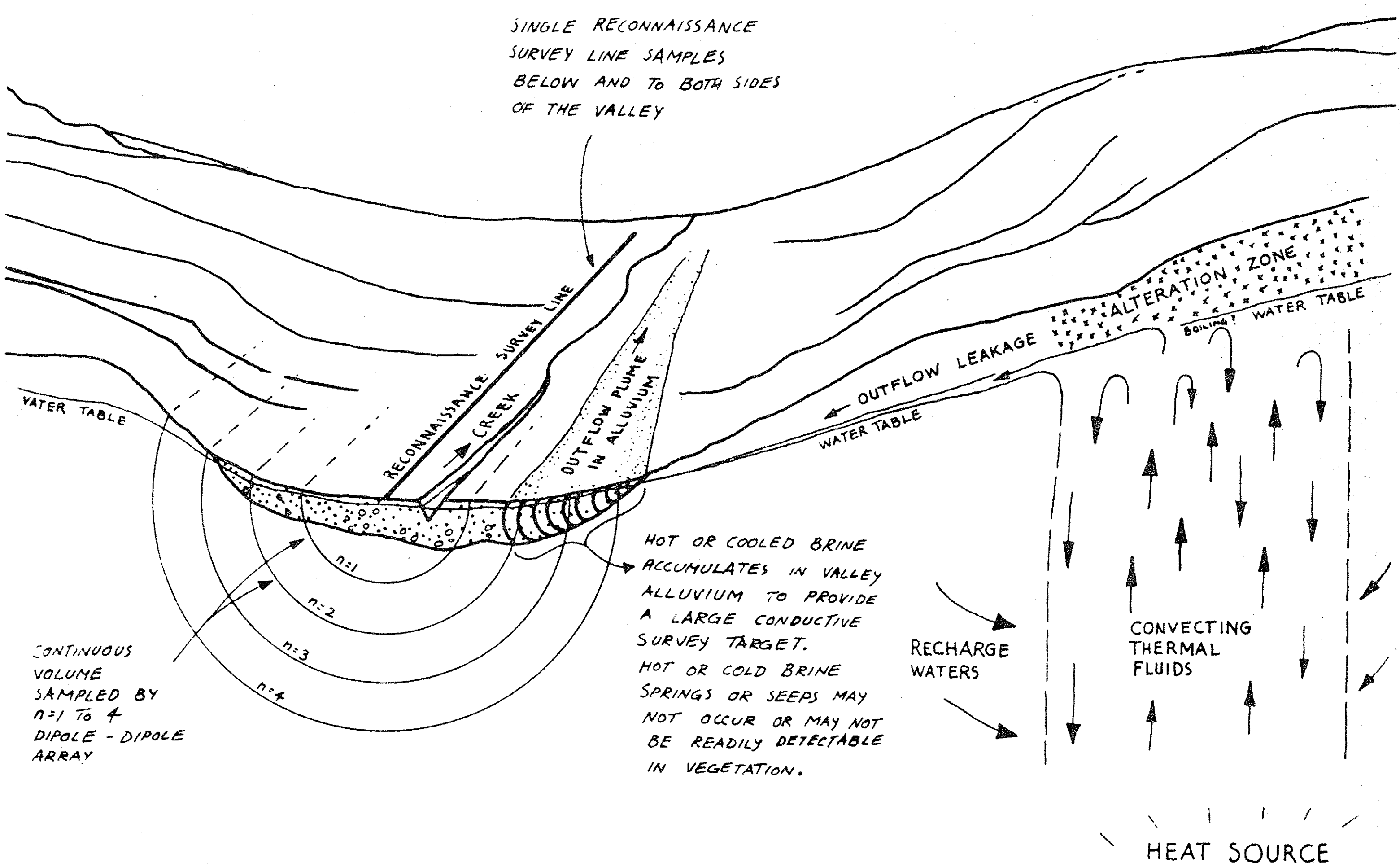



Figure 3.3 LOWER VALLEY RECONNAISSANCE RESISTIVITY LINE DETECTING CONDUCTIVE OUTFLOW LEAKAGE FROM GEOTHERMAL RESERVOIR SOMEWHERE IN THE AREA'S WATERSHED. NO CONVENTIONAL GEOTHERMAL MANIFESTATIONS (SPRINGS, SEEPS) MAY BE VISIBLE.

### 3.2.2 Follow-up resistivity

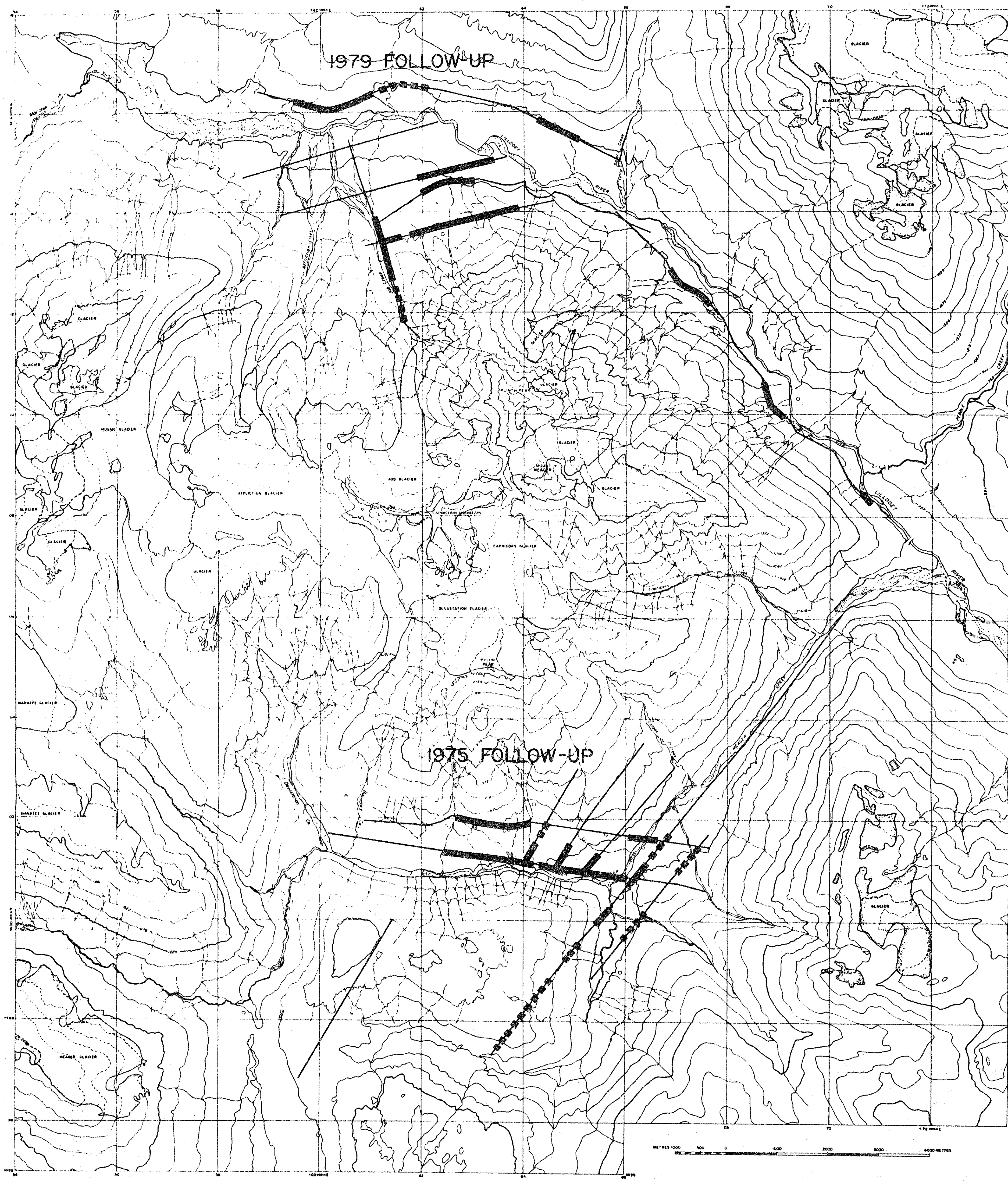
At Meager, the initial discoveries resulting from the single line valley-bottom reconnaissance surveys were detailed with additional resistivity surveys. Figure 3.4 shows the extent of the three anomalous zones after additional dipole-dipole array survey was undertaken.

In the south reservoir area, 1975 follow-up mapped the main area of anomaly within which most of the drilling to date has taken place. This work also isolated the outflow plume along Meager Creek. Drill results matched resistivity results.

At the north anomaly, the areal extent of the anomaly was partially defined, leaving an open boundary uphill to the south, indicating the direction for future exploration. This work took place in 1979.

The South Fork anomaly expression in the 1974 data was not tested until 1980 and 1981, when dipole-dipole survey lines indicated that the South Fork valley was anomalous over much of its length.

Figure 3.5 shows the full results of all resistivity surveys to the end of 1981, except for results from the KRTA alpine area survey which is reported elsewhere. 1978 pole-pole survey in the south reservoir area has extended the anomalous zone high into the volcanics, while isolating the breccia pipe unit as resistive. More dipole-dipole survey on the north side has extended the area of the north anomaly to Job and Affliction Creeks, with a northern cutoff and southward open boundary. Another anomaly is seen on lower Polychrome ridge west of Affliction Creek. In the Lillooet valley, pole-pole survey maps a large lower resistivity unit on the south slopes of the valley, and

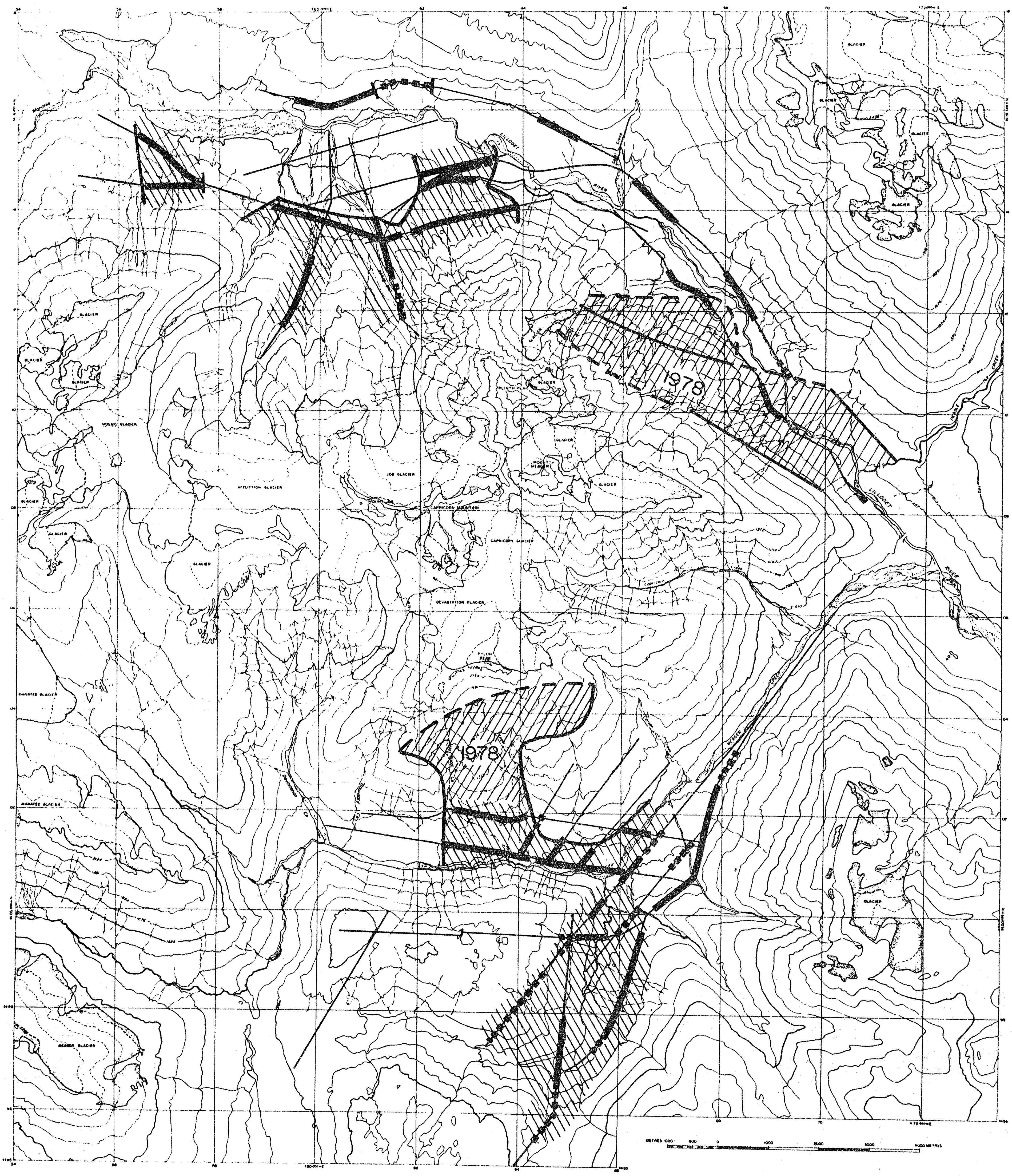



DIPOLE-DIPOLE ARRAY

- DEFINITE RESISTIVITY ANOMALY
- POSSIBLE RESISTIVITY ANOMALY

RESULTS OF FIRST LEVEL OF FOLLOW-UP ON RECONNAISSANCE ANOMALIES

Figure 3.4




DIPOLE-DIPOLE ARRAY

DEFINITE RESISTIVITY ANOMALY

POSSIBLE RESISTIVITY ANOMALY

ANOMALOUS AREA

POLE-POLE ARRAY

ANOMALOUS AREA

## 1978 POLE-POLE RESULTS AND SUBSEQUENT DIPOLE-DIPOLE DETAILING

Figure 3.5

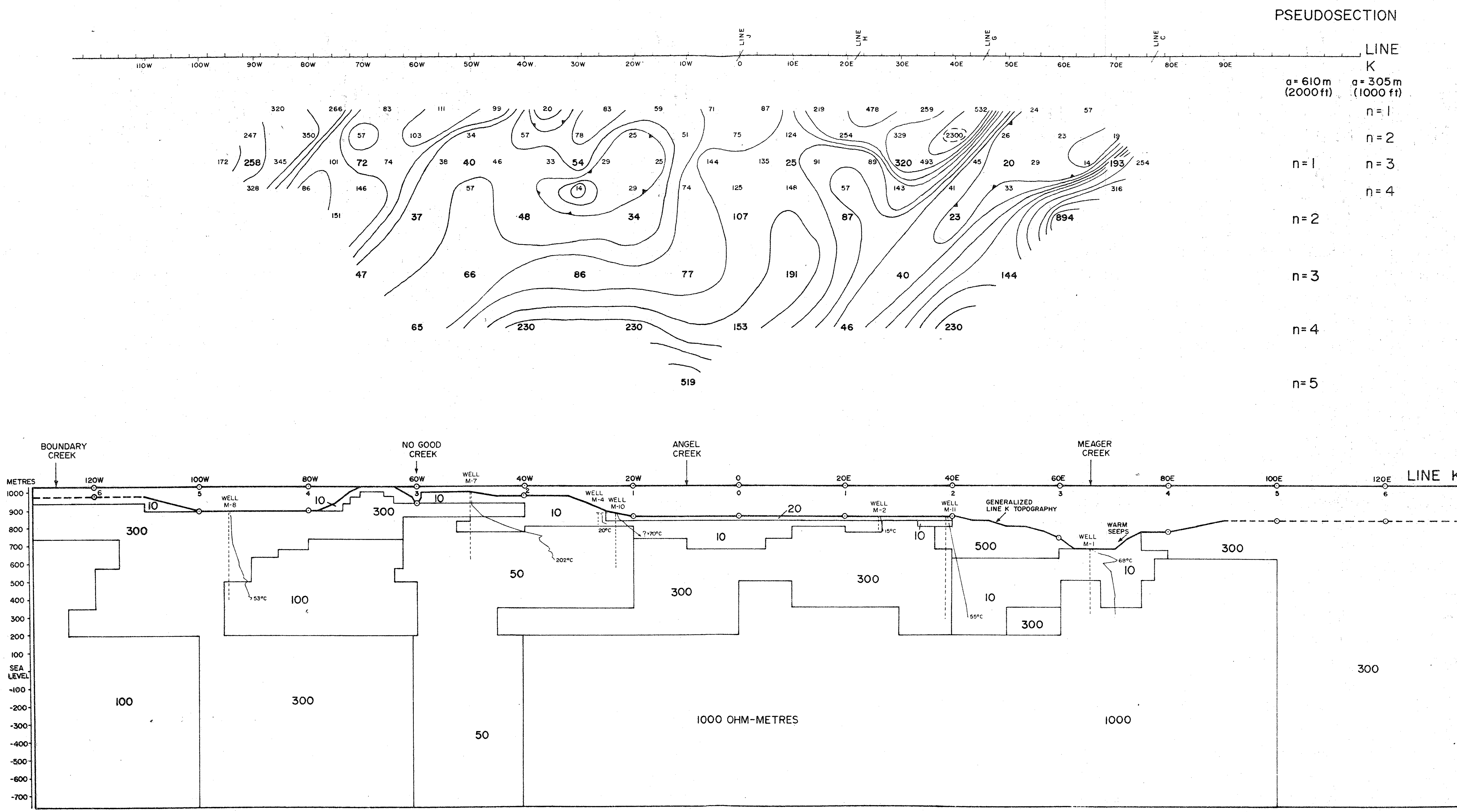
extended dipole-dipole coverage on the north side provides some correlation to 1974 reconnaissance anomalies in the valley.

### 3.2.3 Follow-up analysis

Immediate manual modelling of the 1978 reconnaissance line L anomaly assisted in the decision to place the test well L1-78D immediately adjacent to the anomaly. The resultant high temperature (103°C) and close correlation of temperature curve inflections, core lithology and interpreted model all suggested that modelling of early resistivity data could be very useful.

As a result, 1979 dipole-dipole data in the north anomaly area was extensively modelled, using a one-dimensional inverse method of limited flexibility and potentially substantial ambiguity owing to the necessity for a 1-D simplifying assumption. The results provided some insights into the layering in the area, and suggested strong conductivity beneath the rhyodacite flows in the area. The results have not yet been fully evaluated by drilling or mapping.

As part of the present report, 1975 data from the south reservoir area were submitted to consultants at the University of Utah Research Institute Earth Sciences Laboratory for modelling with an advanced two-dimensional forward modelling system. The results provide a strong case favouring a deep conductive structure on the west side of the south reservoir anomaly, and a very resistive unit on the east half. This correlates with known drill information at present, as does the model's assertion of a conductive lobe extending west of No Good Creek. These were preliminary models which have not taken into consideration any information except the resistivity data themselves; further modelling has been proposed using other available data to refine the result. The south reservoir anomaly and modelling techniques are discussed subsequently in this report.

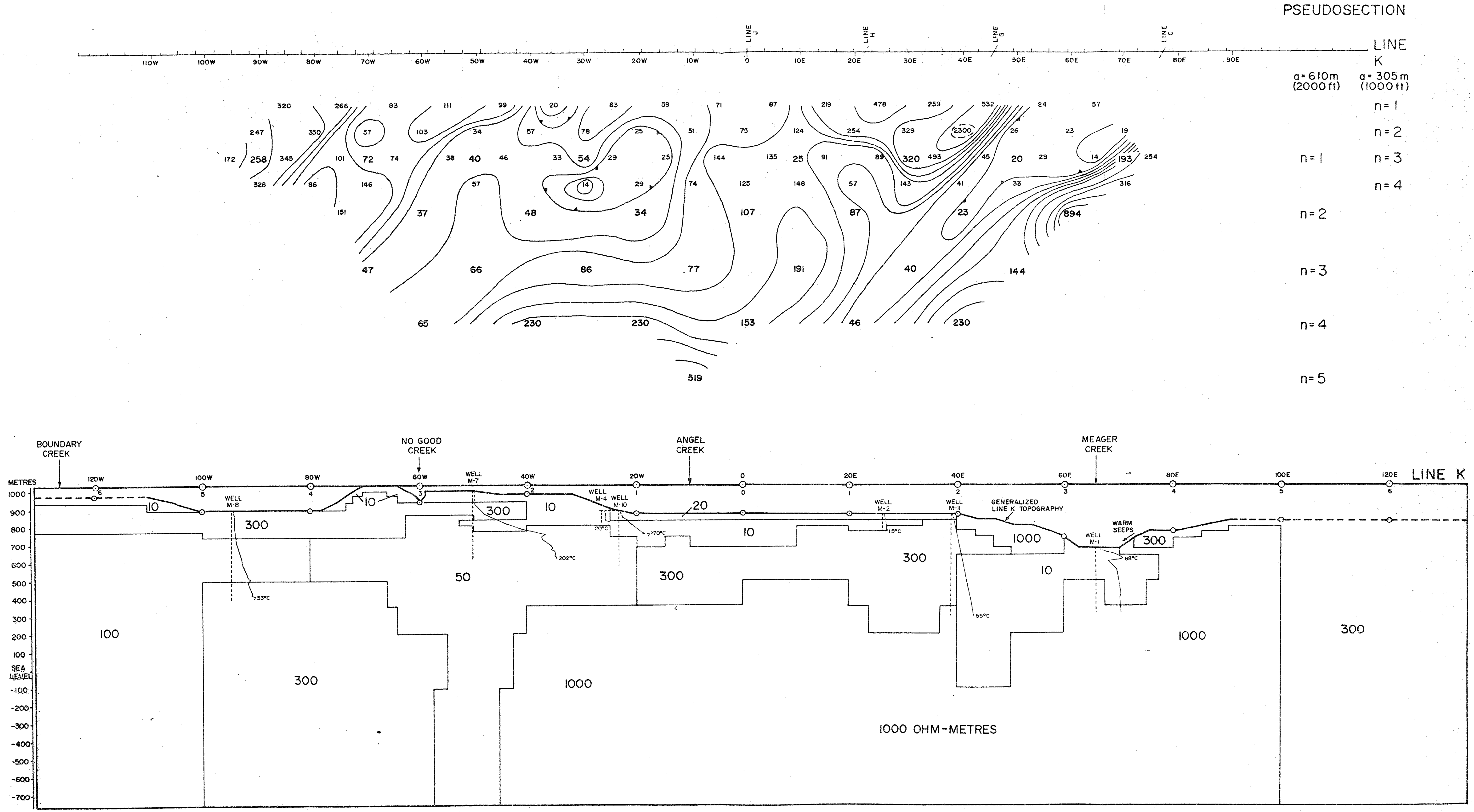



**MODEL A** One result of "IP-2D" (University of Utah Research Institute) forward two-dimensional modelling program. A=610m data only were used. Test well collar elevations are adjusted to fit Line K topography in order to compare temperature profiles with interpreted resistivities.

0 100 200 400 600 800 1000 METRES

Figure 3.6

COMPUTER MODELLING OF RESISTIVITY DATA – LINE K SOUTH RESERVOIR AREA




**MODEL B** One result of "IP-2D" (University of Utah Research Institute) forward two-dimensional modelling program. A=610 m data only were used. Test well collar elevations are adjusted to fit Line K topography in order to compare temperature profiles with interpreted resistivities.

0 100 200 400 600 800 1000
METRES

Figure 3.7

COMPUTER MODELLING OF RESISTIVITY DATA - LINE K SOUTH RESERVOIR AREA

Dr. Stanley Ward was retained by Premier Geophysics in 1981 to review the dipole-dipole data from the Meager area and to comment on its effectiveness and offer interpretive comments. His report is appended. Dr. Ward was not asked to comment on the cost-effectiveness of the surveys, or on the possible merits of other survey approaches.

## 3.3 Summary of resistivity survey approach at Meager Creek

A pattern of step-by-step exploration has been established in which an area of interest is first tested for obvious signs of nearby geothermal activity by sweeping the lower valleys with a dipole-dipole reconnaissance array. A second stage followup survey establishes the shape or partial shape of the anomaly, allowing other tests such as drilling to be sited. Computer-assisted evaluation of some of the data can be applied at any point to guide planning. The result of this two-step routine is the confirmation of geothermal indicators, and if not a direct discovery, a firm indication of the direction from which the measured geothermal manifestation must have originated.

The exploration to this point has been cost-effective by conventional exploration standards. In an attempt to obtain information at higher elevations where no known methods have yet functioned at Meager, very high costs were incurred to develop and test a new method. The pole-pole method was not demonstrated to be capable of routine cost-effectiveness, but in the course of testing, valuable information was obtained about the upper extension of the south reservoir area, and an as-yet unevaluated anomaly was mapped in the Lillooet Valley.

The search continues for methods to obtain cost-effective data from terrain such as that in the central Meager complex. In the interim, valley-bottom dipole-dipole reconnaissance has been shown to be a cost-effective method of determining just where these alpine efforts need to be concentrated.

## 4.0 CHRONOLOGICAL SUMMARIES OF RESISTIVITY SURVEYS

In this section the background and objectives of successive surveys are outlined, and the equipment used and coverage obtained is reported. A brief outline of results is provided.

## 4.1 1974 Dipole-dipole Resistivity Survey

Reconnaissance survey lines in Lillooet and Meager valleys.

### 4.1.1 Background

By the summer of 1974, the Meager Mountain volcanic complex had been selected for intensive exploration for geothermal resources. 1974 was the first year in which a co-ordinated program of geology, geophysics, geochemistry and diamond drill investigations was employed.

Electrical resistivity survey was by 1974 an established leading tool in the world-wide exploration for geothermal reservoirs. A reconnaissance dipole-dipole survey approach was planned and managed by Nevin Sadlier-Brown Goodbrand Ltd. The geophysical contractor was McPhar Geophysics Ltd. of Vancouver.

### 4.1.2 Survey Objectives

The reconnaissance resistivity survey was intended to provide an initial evaluation of the electrical characteristics of the overburden and bedrock in a line encircling much of the volcanic complex. The principal geothermal manifestations at that time were the Meager Creek Hot Springs and the Pebble Creek Hot Springs. The survey lines were designed to approach and pass over the area near both of these hot springs. It was expected that this initial reconnaissance survey would identify specific areas of anomalous low resistivity in which to conduct more detailed exploration.

### 4.1.3 Method and Coverage

**Logistics:** In 1974 the logging road along the southwest bank of the Lillooet River terminated about six miles southeast of the confluence of Meager Creek and the Lillooet River. Access to the prospect was accomplished by helicopter operating from the end of the road. A tent camp was established, and for most of the survey the geophysical crew was set out by helicopter in the morning and picked up in the evening to return to camp. A crew of linecutters cut and chained the survey lines, and cleared helicopter landing pads at intervals along the survey line.

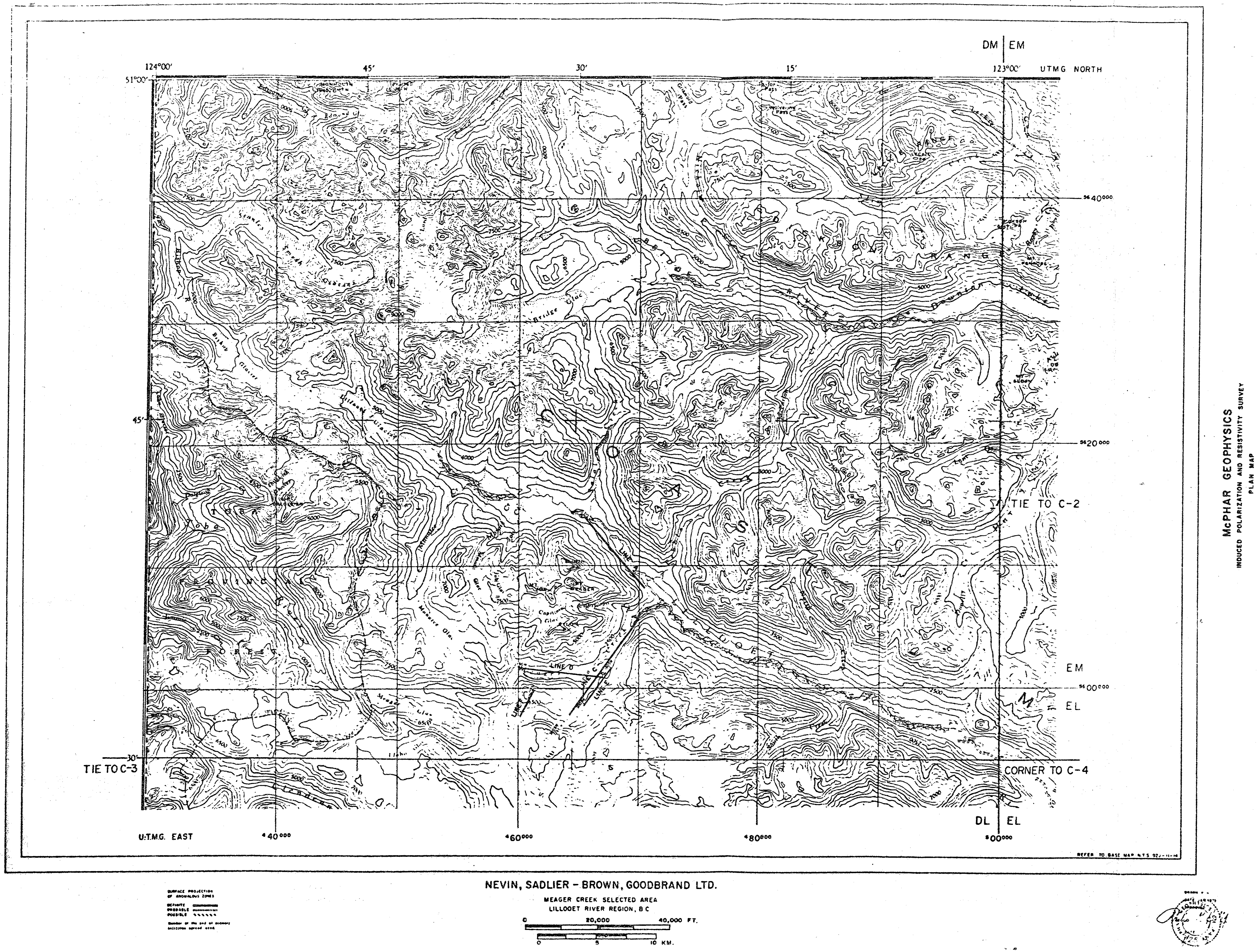
Equipment: Transmitter: McPhar 1 kw reversing square wave at 0.13 Hz.
Receiver: McPhar frequency domain induced polarization and resistivity receiver.
Communications: citizens band walkie-talkies.

Arrays: Dipole-dipole, a=1,000 feet, n=1 to 4.
Dipole-dipole, a=500 feet, n=1 to 4 (detail line).

Coverage: The survey lines were located on the lower slopes or valley floor on three sides of the Meager Mountain volcanic complex. A long line (A) extended along the southwest side of the Lillooet River from Salal Creek to approximately Pebble Creek. Survey line C was placed along the southeast side of Meager Creek from Capricorn Creek, through the Meager Creek Hot Springs area, and up into the South Fork area of Meager Creek. Line D followed the westerly reach of Meager Creek on the south side of the complex. Two other short lines (E,F) were also placed in the south complex. The location of the survey lines is shown in Figure 4.1

### 4.1.4 Results

Approximately 360 resistivity measurements were obtained on five survey lines extending over a distance of approximately 37 line km (23 line miles). Anomalies were identified on four of the five survey lines. Six definite anomalies and numerous probable and possible anomalies were identified.

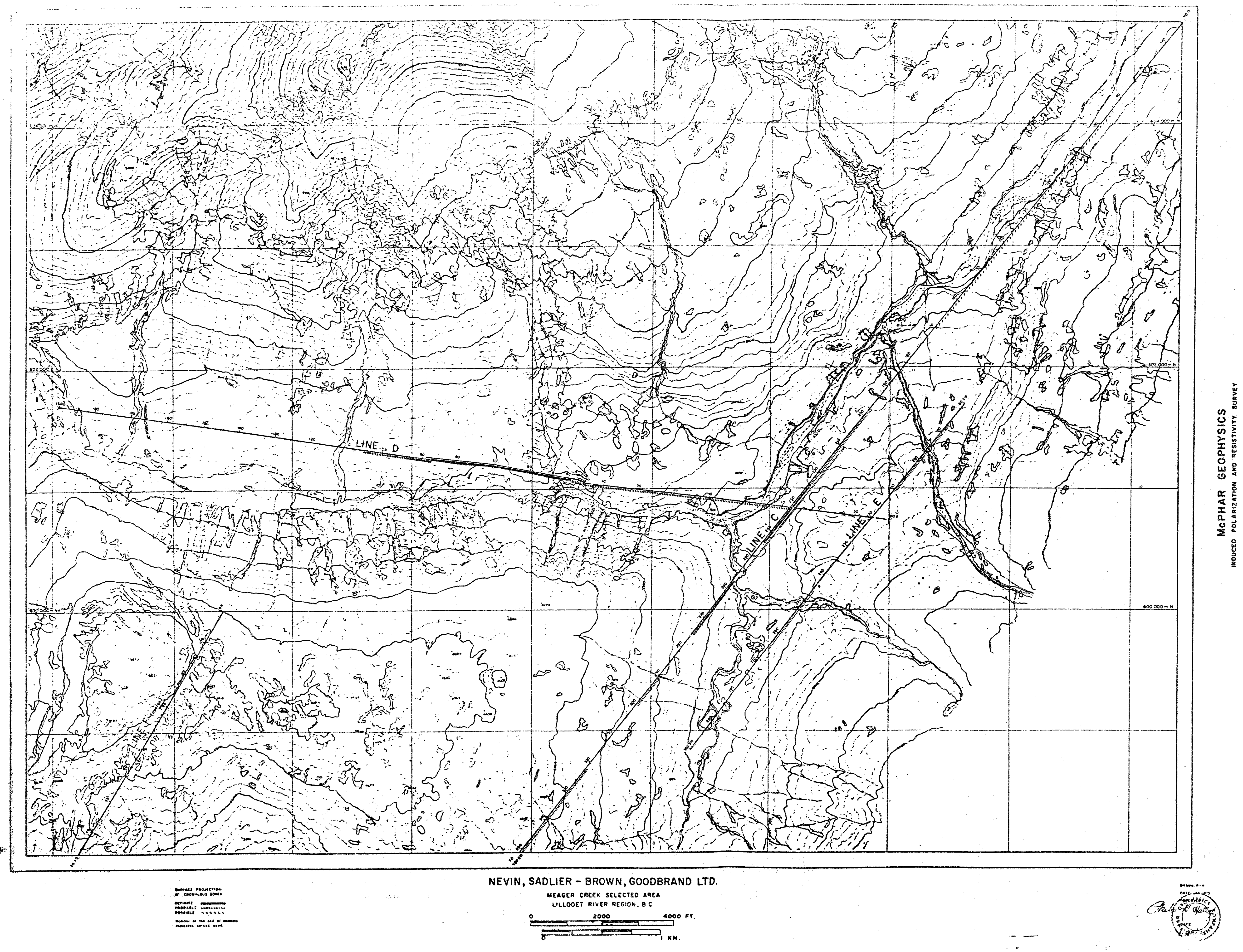



Location of 1974 dipole-dipole reconnaissance resistivity lines.

The lines circle the south, east and northeast flanks of the volcanic complex.

Figure 4.1

from report # GP1A-1974-1




1974 summary map showing dipole-dipole resistivity anomalies.

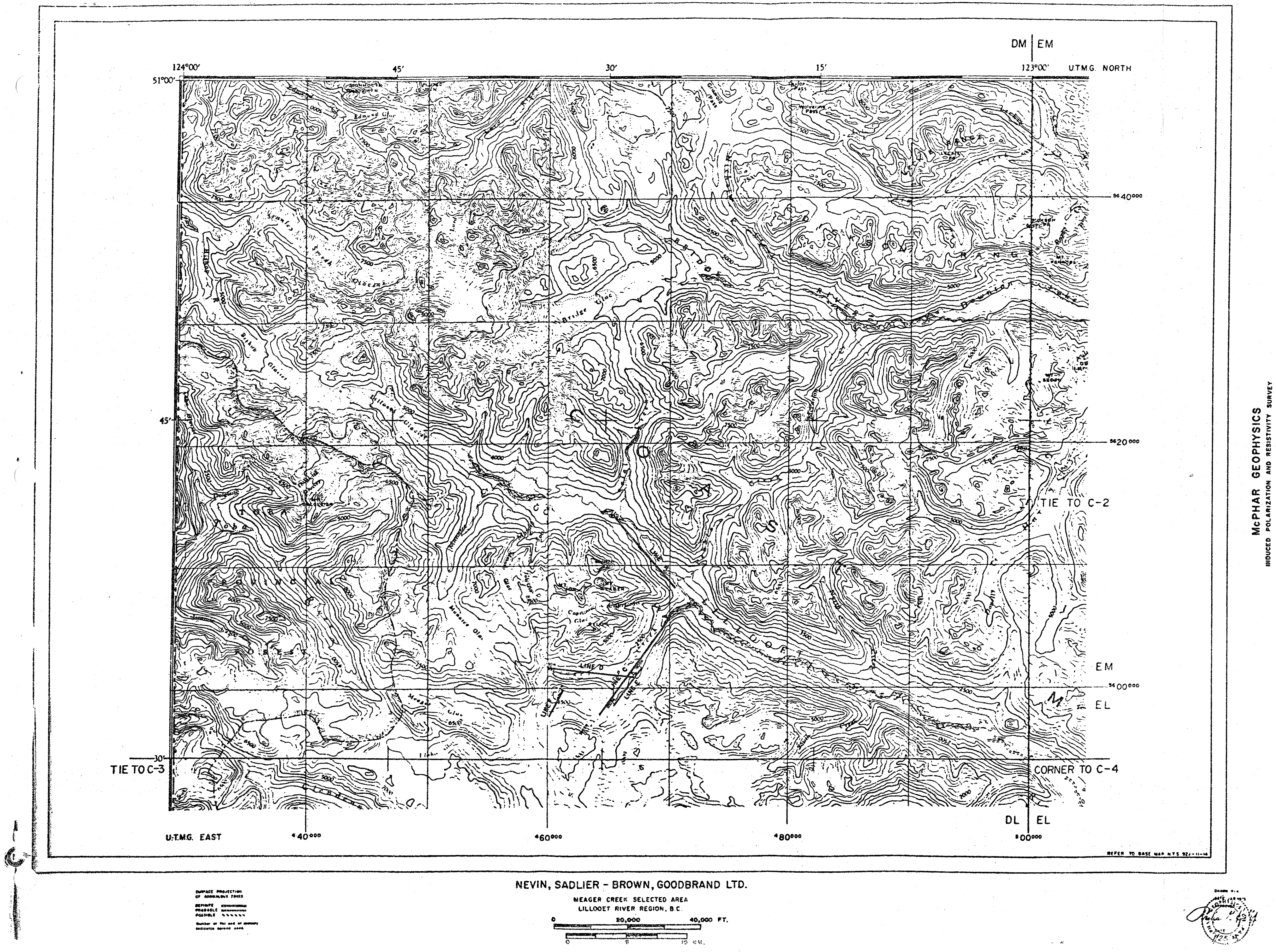
The line D anomaly is the South Reservoir "discovery anomaly".

The line C anomalies relate to salinity in Meager Creek sediments (upper anomaly) and in South Fork Creek sediments ( lower anomaly).

Both areas of current exploration interest on the south side were thus indicated in the 1974 initial resistivity reconnaissance.

Figure 4.2

from report # GP1A-1974-1

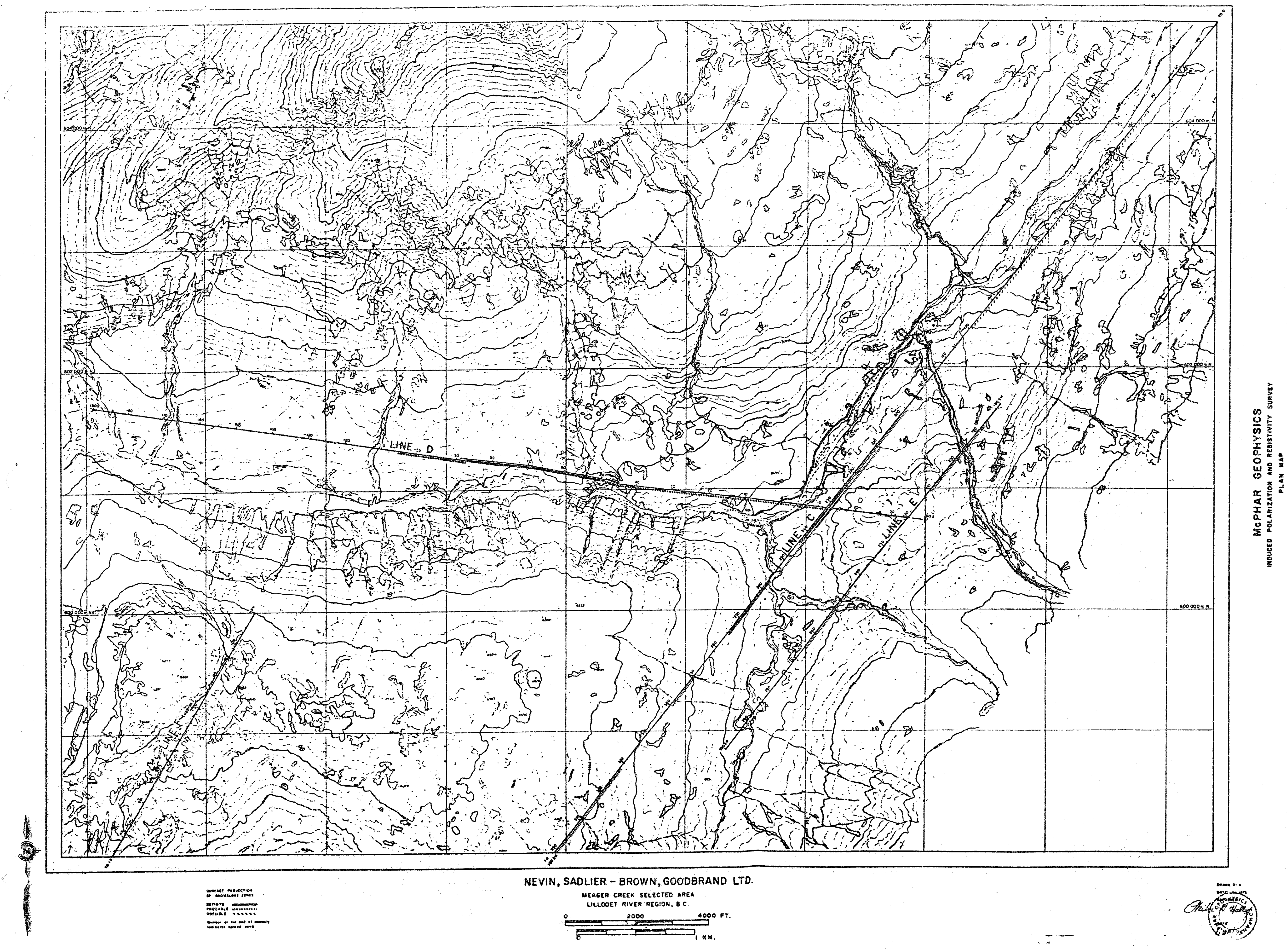



Location of 1974 dipole-dipole reconnaissance resistivity lines.

The lines circle the south, east and northeast flanks of the volcanic complex.

Figure 4.1

from report # GP1A-1974-1




1974 summary map showing dipole-dipole resistivity anomalies.

The line D anomaly is the South Reservoir "discovery anomaly".

The line C anomalies relate to salinity in Meager Creek sediments (upper anomaly) and in South Fork Creek sediments ( lower anomaly).

Both areas of current exploration interest on the south side were thus indicated in the 1974 initial resistivity reconnaissance.

Figure 4.2

from report # GP1A-1974-1

## 4.2 1975 Dipole-dipole Resistivity Survey

Dipole-dipole detailed survey on south side of the Meager Complex.

### 4.2.1 Background

The 1974 reconnaissance dipole-dipole survey (4.1) had provided several resistivity anomalies surrounding the volcanic complex. Based on the results of the integrated exploration program initiated in 1974, Nevin Sadlier-Brown Goodbrand Ltd. selected the south flank of the Meager mountain volcanic complex as the site of the majority of 1975 exploration activity.

Additional dipole-dipole survey lines were planned for the south flank of the complex, to more fully define the location and extent of the resistivity anomalies measured on 1974 reconnaissance lines C, D and E. Greg Shore of Deep Grid Analysis Ltd. was the geophysical consultant and contractor for this work.

### 4.2.2 Survey Objectives

The 1975 dipole-dipole survey was intended to define the lateral extent and depth characteristic of the anomaly on 1974 line D, and to further define the nature of the anomalous expressions on 1974 lines C and E.

### 4.2.3 Method and Coverage

Logistics: In the summer of 1975, access to the exploration area continued to be accomplished by helicopter operating from the end of the logging road. A tent camp was established beside Angel Creek on the south flank of the complex. A crew of linecutters based in the camp cut and chained the survey lines. The entire 1975 survey program was conducted from this camp, without the day to day assistance of a helicopter.

Equipment: The measured data showed that the 1974 survey equipment was operating at its maximum power and resolution in much of the 1974 survey. With the requirement for larger arrays and greater "n" separations for the 1975 detailed survey program, a different set of instrumentation was used.

Transmitter: DGA, 40 kw, reversing square wave at 0.016 Hz.
Receiver: Hewlett-Packard 970A millivoltmeter.
Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Arrays: Dipole-dipole, a=1,000 feet, n=1 to 4.
Dipole-dipole, a-2,000 feet, n=1 to 7.

Coverage: 1974 line D was resurveyed with the larger (a=2,000 feet) arrays. A new line (K) was established along the break in slope north of and parallel to line D. This line was surveyed twice, at a=1,000 and at a=2,000 feet. Three additional detail lines, G, H and J, were established striking northeast from line D, crossing line K, in the area between Angel Creek and the northeast reach of Meager Creek, and were surveyed at a=1,000 feet.

The line locations are shown in Figure 4.3.

### 4.2.4 Results

The results of the 1975 dipole-dipole survey line provided some lateral definition of the 1974 line D resistivity anomaly, to define a broad anomalous zone (A) and an apparent outflow plume along the Meager Creek Valley ($B_1$, $B_2$) as shown in Figure 4.3.

## 4.3 1976 3-Array Shallow Resistivity Soundings

Seven shallow soundings in the Lillooet-Pebble Creek area.

### 4.3.1 Background

The 1975 dipole-dipole surveys extended the definition of the 1974 resistivity anomaly on line D to the practical limit of conventional resistivity instrumentation and field techniques.

1976 was essentially a year of program review. The geophysical fieldwork consisted of a large self-potential survey in the Lillooet River valley, and a two day program of vertical electrical soundings in the Lillooet River-Pebble Creek area.

### 4.3.2 Survey Objectives

The soundings were intended to measure the resistivity of the valley sediments near two of the three 1974 line A anomalies.

### 4.3.3 Method and Coverage

Logistics: By September of 1975 a logging road extended along the northeast side of the Lillooet River to a point just short of Pebble Creek. Most of the soundings were operated from a 2-man camp at the head of the logging road, using portable equipment and accessing the survey sites by foot. A canoe was used to cross to the southwest side of the Lillooet River for the soundings in that area.

Equipment: Transmitter: Huntec M-3, 200 watts, reversing square wave, 50% duty cycle, at 0.125 Hz.

Receiver: Hewlett-Packard 970A millivoltmeter.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Arrays: Expanding 3-array spreads were used, with spacings (a) of 10, 20, 40, 80, 160, 320, 640, 1250 and 2500 feet.

Coverage: Soundings S-1 and S-2 were placed on the southwest side of the Lillooet River between Pebble Creek and Meager Creek. Soundings S-3 and S-4 were similarly located, but on the northeast side of the Lillooet River. These four soundings were intended to test for conductive materials suggested in the 1974 line A anomaly at Pebble Creek. Soundings S-5, S-6 and S-7 were placed at 1 km intervals northwest from Pebble Creek on the northeast side of the Lillooet River.

### 4.3.4 Results

Soundings S-1, S-2, S-3 and S-4, all located downstream from Pebble Creek on both sides of the Lillooet River, indicate anomalous low resistivity valley fill. Soundings S-5 and S-6 indicate somewhat less conductive valley fill, and sounding S-7 shows little sign of anomalous conductivity, which may result from its location in an area of limited overburden.

The results serve to confirm that near surface anomalous low resistivities occur in the Lillooet River valley downstream from Pebble Creek.

## 4.4 1977 Multiple Pole-pole Resistivity Survey

Multiple pole-pole survey attempt, Lillooet-Pebble Creek area.

### 4.4.1 Background

By the end of 1975, most of the accessible ground on the lower slopes of the volcanic complex had been surveyed. Much of the complex remained untested, due to the extremely steep nature of the higher terrain. Geophysical consultant Greg Shore proposed in 1977 to design and operate a multiple electrode survey array which would permit the measurement of resistivities throughout the extremely rough topography. The proposed method would eliminate the need for regularly spaced collinear arrays, and would permit effective survey coverage based on indirectly accessed survey electrode locations. The basic measurement array would be a conventional pole-pole array.

### 4.4.2 Survey Objectives

The objective of the 1977 program was to obtain survey results throughout the area of the confluence of Meager Creek with the Lillooet River, an area known from 1974 and 1976 resistivity measurements to be anomalously conductive.

### 4.4.3 Method and Coverage

Logistics: By the summer of 1977, a good quality logging road extended to Pebble Creek on the northeast side of the Lillooet River. There was still no road access to the southwest side of the Lillooet River or the Meager Creek Valley. Access to that side was accomplished initially by helicopter, and later by means of a rubber boat secured to a fixed cable spanning the river.

A helicopter was used extensively in the placement of survey wires between the central operating station and the surrounding peaks and intermediate high areas.

Equipment: Transmitter: DGA, 40 kw, reversing square wave at 0.25 Hz.

Receiver: Hewlett-Packard 3456A microvoltmeter.

Overall Control: Hewlett-Packard 9825A computer controlled the transmitter, receiver, and input scanner.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Wire and tools: conventional backpack reels and spools, and helicopter-carried Turair wire dispenser.

Arrays: Multiple pole-pole array measurements, variable separation, variable orientation.

Coverage: A single multiple pole-pole array instalation covered the valley area around the confluence of Meager Creek with the Lillooet River. Electrodes were extended to the upper slopes of the surrounding mountains, and electrode positions were placed on the lower slopes and valley floor area.

### 4.4.4 Results

The results contained an unacceptably high level of ambiguity, which permitted only the most general observations that the valley area was generally anomalously conductive near surface and probably conductive at substantial depth. The distribution and orientation pattern of the data was irregular and of low density. Part of the reason for this was the fact that the majority of the field operation time was spent trouble-shooting this ioneer array development.

## 4.5 1978 Multiple Pole-pole Resistivity Surveys

Multiple pole-pole survey, Lillooet Valley.

### 4.5.1 Background

The 1977 pole-pole survey provided very little useful survey information. The 1977 data lacked sufficient density and regularity of spacing to permit straightforward interpretation. This factor, combined with a need to improve the array layout efficiencies, led to the design of the 1978 pole-pole survey method.

### 4.5.2 Survey Objectives

The 1978 pole-pole survey work was intended to provide resistivity information from the upper valley slopes above existing dipole-dipole anomalies located on line A in the Lillooet River valley.

### 4.5.3 Method and Coverage

Logistics: The logging road on the northeast side of the Lillooet River extended as far as Pebble Creek. A bridge was installed at Pebble Creek and a tote road extended approximately two kilometres northwest of Pebble Creek. A tent camp was established near the road at Pebble Creek.

A bridge over Meager Creek was in place, and a logging road extended in to the south reservoir area on the south side of the volcanic complex. These roads were used as much as possible in course of operating the 1978 pole-pole survey. The survey method required the daily use of a light helicopter which was stationed in camp.

Equipment: Transmitter: Huntec M-3, 200 watts, reversing square wave, 50% duty cycle, at 0.125 Hz.

Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

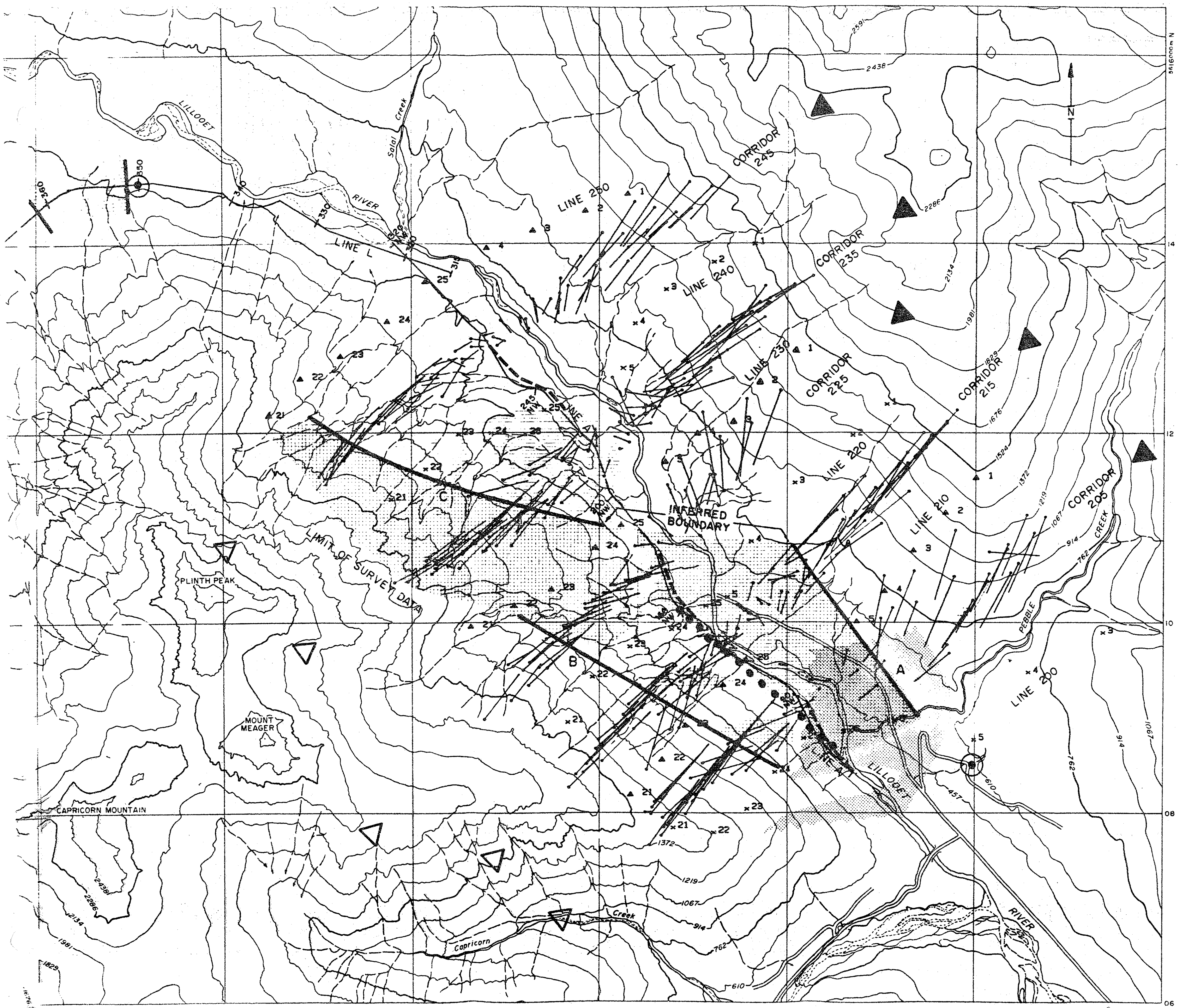
Wire Tools: conventional backpack reel and spool units, and Turair airborne wire dispenser.

Arrays: Multiple pole-pole array measurements, variable separation, variable orientation.

Coverage: The array layout and area covered is outlined in Figure 4.4. The survey area covered the valley of the Lilloet River and both slopes up to treeline from Pebble Creek northwest to within one kilometre of Salal Creek.

4.5.4 Results:

The survey data indicated a broad WNW trending resistivity anomaly extending from the vicinity of Pebble Creek diagonally upslope toward the upper northern slopes of Plinth Peak. A deep anomalous resistivity zone was indicated under the southwest valley slopes extending to a point approximately beneath the Pebble Creek hot springs. The overall anomaly is known as the Lillooet Valley Resistivity Anomaly.




LEGEND

POLE-POLE RESISTIVITY SURVEY 1978

| | |
|---|---|
| ▲5 | Location of survey current electrode |
| x 3 | Location of survey potential electrode |
| LINE 240 | Survey electrode line |
| CORRIDOR 245 | Survey data grouping for pseudosectional plots |
| ▷ ◀ | Indicates position and limits of x-axis of corridor pseudosectional plot |
| | Plan position of measurement plotting point at depth |
| | Plan position of bisectrix of line between the two electrode locations used for the reading |

DIPOLE-DIPOLE RESISTIVITY SURVEYS, 1974, 1978

| | |
|---|---|
| 350W | Survey line and station, 1978 |
| 100NW | Survey line and station, 1974 |

INTERPRETATION

LOW RESISTIVITY ZONES

| | |
|---|---|
| | Shallow (<1000metres) |
| | Deep (>1000metres) |
| | Resistivity Contact |
| | Southwest limit of Conductive Valley Sediments |
| | 1974 Dipole-Dipole Resistivity anomaly |
| | Diamond drill hole |
| | 1977 Pole-Pole Resistivity anomaly (Deep) |

0 400 800 1200 1600 2000

METRES

1977-78 Geophysical data by Deep Grid Analysis (1977) Ltd., Vancouver, B.C.
1974 Geophysical data by McPhar Geophysics Ltd., Vancouver, B.C.

Figure 4·6

GEOPHYSICAL DATA LOCATION AND SUMMARY RESULTS LILLOOET MAP AREA

*FROM REPORT #GPIA-1978-1*

## 4.6 1978 Multiple Pole-Pole Resistivity Surveys

Multiple pole-pole survey, South Meager area.

### 4.6.1 Background

The 1977 pole-pole survey provided very little useful survey information. The 1977 data lacked sufficient density and regularity of spacing to permit straightforward interpretation. This factor, combined with a need to improve the array layout efficiencies, led to the design of the 1978 pole-pole survey method.

### 4.6.2 Survey Objectives

The 1978 pole-pole survey work was intended to provide resistivity information from the upper slopes above the developing South Reservoir area.

### 4.6.3 Method and Coverage

Logistics: The logging road on the northeast side of the Lillooet River extended as far as Pebble Creek. A bridge was installed at Pebble Creek and a tote road extended approximately two kilometres northwest of Pebble Creek. A tent camp was established near the road at Pebble Creek.

A bridge over Meager Creek was in place, and a logging road extended in to the south reservoir area on the south side of the volcanic complex. These roads were used as much as possible in course of operating the 1978 pole-pole survey. The survey method required the daily use of a light helicopter which was stationed in camp.

Equipment: Transmitter: Hunted M-3, 200 watts, reversing square wave, 50% duty cycle, at 0.125 Hz.
Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.
Communications: Motorola walkie-talkies and base station, assigned frequency in business band.
Wire Tools: conventional backpack reel and spool units, and Turair airborne wire dispenser.

Arrays: Multiple pole-pole array measurements, variable separation, variable orientation, supplemented by one line of in-line pole-pole measurements.

Coverage: The array layout and area covered is outlined in Figure 4.6.1. Six corridors of measurements extended from the high alpine to the lower valley on the south side of the volcanic complex, bracketing the South Reservoir area.

4.6.4 Results:

The survey results extended the South Reservoir resistivity anomaly substantially northward into the volcanics. A conductive response was also obtained from volcanics lying to the east and west of the northward projection of the South Reservoir zone, raising the possibility that the volcanic flow units on the south flank of Pylon Peak are inherently conductive, perhaps due to weathering. A notable exception is a resistive signature obtained in the breccia pipe zone east of Angel Creek.

Resistive measurements obtained from the few electrodes located near Meager Creek suggested a south boundary for the South Reservoir anomaly, as shown on figure 4.5.


## LEGEND

**POLE-POLE RESISTIVITY SURVEY 1978**

| | |
|---|---|
| ▲5 | Location of survey current electrode |
| x3 | Location of survey potential electrode |
| LINE 650 | Survey electrode line |
| CORRIDOR 655 | Survey data grouping for pseudosectional plots |
| ▷ ◀ | Indicates position and limits of x-axis of corridor pseudosectional plot |
| | Plan position of measurement plotting point at depth |
| | Plan position of bisectrix of line between the two electrode locations used for the reading |

**DIPOLE-DIPOLE RESISTIVITY SURVEYS**

| | |
|---|---|
| 50W | Survey line and station, 1974, 1975 |

**INTERPRETATION**

LOW RESISTIVITY ZONES

| | |
|---|---|
| | Shallow (< 1000 metres) |
| | Deep (>1000 metres) |
| | Resistivity Contact |
| ● | Diamond drill hole |

0 200 400 600 800 1000

METRES

1975-78 Geophysical data by Deep Grid Analysis (1977) Ltd., Vancouver, B.C.
1974 Geophysical data by McPhar Geophysics Ltd., Vancouver, B.C.

Figure 4·1

GEOPHYSICAL DATA LOCATION AND SUMMARY RESULTS MEAGER MAP AREA

*FROM REPORT #GPIA-1978-1*

## 4.7 1978 Dipole-dipole Resistivity Survey

Single reconnaissance line on north side.

### 4.7.1 Background

The 1978 multiple pole-pole survey in the Lillooet valley had been completed, with the data extending northwest almost to Salal Creek. A test drill hole was being planned for some position on the north flank of Plinth Peak, an area without previous resistivity investigation.

### 4.7.2 Survey Objective

The dipole-dipole reconnaissance line was intended to extend reconnaissance resistivity coverage from the northwest end of line A (1974) west across the base of the north flank of Plinth Peak. The results of this reconnaissance line would be considered in the final selection of a drill site in the area.

### 4.7.3 Method and Coverage

Logistics: There was no road access into the survey area in 1978. The resistivity crew was housed at the tent camp at Pebble Creek and taxied to and from the exploration area each day by helicopter.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.25 Hz.

Receiver: Hewlett-Packard 3465B 4 1/2 digit microvoltmeter

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Arrays: Dipole-dipole, a=300 metres, n=1 to 5.

Coverage: 1978 line L extended from the northwest end of 1974 line A west along the break in slope below Plinth Peak, to its terminus at Affliction Creek. Effective measurement coverage stopped at Job Creek.

### 4.7.4 Results

A single substantial resistivity low was observed between 351W and 361W on line L. Initial subjective interpretation (later confirmed by a 2-D computer inversion) indicated a kilometre wide zone of 200 ohm-metres resistivity capped by a 250 metre thickness of 1,000 ohm-metres resistivity material. Flanking this feature to east and west were rocks of a mean 500 ohm-metres resistivity. The proposed site of the research well L1-78D was moved to a point 100 metres east of the anomaly, where bedrock appeared to be near-surface.

## 4.8 1979 Dipole-dipole Resistivity Surveys

Dipole-dipole reconnaissance and detail surveys, north side.

### 4.8.1 Background

By 1979, an area of exploration interest had been defined on the north side of the complex by geological mapping and inference, by the 1978 dipole-dipole resistivity survey line L, and by a 605 metre diamond drill hole (L1-78D). An anomaly on line L had indicated a zone of low resistivity beneath a cap of high resistivity. The adjacent test well L1-78D yielded a maximum temperature of 102.8°C at its deepest point (573.3 metres), and a temperature gradient of 210°C/km.

### 4.8.2 Survey Objectives

The 1979 survey was intended to expand resistivity coverage in the area around the 1978 resistivity anomaly and high-temperature test well L1-78D.

### 4.8.3 Method and Coverage

Logistics: The 1979 survey area was approximately 7 kilometres northwest of the end of the nearest logging road in the Lillooet River Valley. A tent camp was installed at the site of the 1978 drilling camp on the south side of the Lillooet River. From this base, survey lines were cut and chained, and the entire resistivity survey south of the Lillooet River was operated. The camp was serviced by occasional helicopter supply flights, but the survey operations were undertaken entirely on foot.

The camp was moved by helicopter to a sandbar on the north side of the Lillooet River, providing access to survey line Q on the north side of the river.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.25 Hz.
Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.
Communications: citizens band walkie-talkies and base station.

Arrays: Dipole-dipole, a=300 metres, n=1 through 7.

Coverage: A total of 38 line km (24 line miles) of survey was undertaken. A four line grid was installed to bracket the 1978 line L anomaly on the south, west and north sides. Survey coverage was extended to the north side of the Lillooet River by measuring on a line installed along the break in slope.

4.8.4 Results:

The 1979 results showed that 1978 line L anomaly L-1 is part of a large anomalous area extending southward up the slopes, and remaining open to the south, west, and possibly northeast. On the north side of the river, three anomalies were noted. A total of seven one-dimensional inversions were made on the data by Phoenix Geophysics of Toronto. Two test wells (L2-80D and L3-80D) were sited partially on the basis of the resistivity anomaly.

## 4.9 1980 Dipole-dipole Resistivity Survey

Dipole-dipole traverse, Lillooet Valley, north side of complex.

### 4.9.1 Background

On the north side of the complex, the 1979 program of dipole-dipole survey had substantially extended the areal extent of the 1978 line L anomaly, and had identified new anomalous areas on the north side of the Lillooet River.

### 4.9.2 Survey Objectives

Survey line V was intended to determine the eastern boundary of the north resistivity anomaly, and provide further information about anomaly Q-3 on line Q north of the Lillooet River. The extension of line V down the northeast side of the Lillooet River toward Pebble Creek would provide detailed measurements from the north side of the Lillooet River behind Pebble Creek Hot Springs (which has been broadly sampled by multiple pole-pole survey in 1978).

A secondary objective was to obtain overlapping a=300 metre dipole data and a=600 metre dipole data, in order to permit evaluation of the resolution characteristics of both arrays. These overlapping data could be obtained from the same arrays, operating from vehicles on the road at negligible increased cost as compared to a single a=300 metre survey.

### 4.9.3 Method and Coverage

Logistics: Line V was operated along the general route of the access road between the B. C. Hydro main camp and Job Creek. The survey line left the road wherever necessary to maintain a reasonably straight line. The survey crew was housed at the B. C. Hydro main camp.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.125 Hz.
Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.
Communications: citizens band walkie-talkies and base station.

Arrays: Dipole-dipole a=300 metres, n=1 through 15.
Dipole-dipole a-600 metres, n=1 through 7.

Coverage: Line V extended from Job Creek, following the route of the access road east toward the B. C. Hydro main camp. The line crossed to the north side of the Lillooet River and continued east and southeast to a point approximately two kilometres west of the B. C. Hydro main camp.

### 4.9.4 Results

Line V establishes an eastern and north eastern boundary for the north anomaly zone. Two anomalies are identified on the northeast side of the Lillooet River, one located just east of Salal Creek, and the other located east of the Pebble Creek Hot Springs. The east end of the line appears to be approaching a low resistivity zone.

## 4.10 1980 Dipole-dipole Resistivity Survey

Dipole-dipole traverses, Meager Creek and South Fork Area.

### 4.10.1 Background

On the south side of the complex, a re-evaluation of 1974 dipole-dipole reconnaissance data emphasized existing anomalies in the South Fork Creek area as being potentially significant.

### 4.10.2 Survey Objectives

Survey line S, T and U were designed to extend the information about the anomalous indications obtained in 1974 and 1975. The data would also test for evidence of a south or southeast extension of the South Reservoir zone.

### 4.10.3 Method and Coverage

Logistics: Logging road provided access to several points on line S.

Most of line S was surveyed using equipment backpacked in.

The lower portion of line T near South Fork Creek was operated with backpacked equipment. The upper portion of line T was operated from a fly camp located near the lake on the line.

Line U was completed in 4 days using a helicopter to drop the survey crew in the alpine areas on both sides of the valley. The crew would work down to the road and return to the main camp.

Delays were experienced on line U and line S due to road blockages by logging equipment. Line U operation was further hampered by poor radio operation. Both lines S and U suffered severe disruption caused by large scale slash burning started without advance notice by the forestry department. The fires engulfed the survey route on two occasions with resultant loss of installed wire arrays on line S, and the loss of vital transmitter notes during a rush evacuation of transmitter equipment from the second fire area. The cost of these difficulties to the program were the extension of line S time requirements (by three days), and the complete loss of line U data usefulness, (at a cost of four days operation).

When not occupying the fly camp on line T, the crew boarded at the main camp facilities of B. C. Hydro near Pebble Creek.

<u>Equipment</u>: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.125 Hz.

Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.

Communications: citizens band walkie-talkies and base station.

Wire and Equipment: Conventional back-pack reel and spool units, using disposable, pre-measured five-spread arrays.

<u>Arrays</u>: Dipole-dipole, a=300 metres, n=1 through 8, occasionally greater than n=8.

Coverage: Line S extends along the southwest side of Meager Creek at the break in slope, from north of the Meager Creek Hot Springs south to Barr Creek and up the South Fork Creek valley. Line T branches off from line S at Barr Creek, running west across the South Fork Creek and passing south of the South Reservoir zone.

4.10.4 Results

Lines S and T produced several anomalies apparently associated with the drainage of the South Fork Creek. Test well M12-80D drilled in their midst yielded only moderate temperatures, but highly saline brine under an artesian head. An enigmatic anomaly (S-1) located west of the Meager Creek Hot Springs at Hot Springs Creek can not be interpreted on the basis of present data, but is suggestive of near-surface lateral flow of saline fluids, rather than a deep low resistivity anomaly.

## 5.0 SUMMARY OF AREA COVERAGE

Figure 5.1 (in pocket) shows the extent to survey coverage by dipole-dipole and pole-pole surveys, and the location of some vertical electrical sounding results.

The method used to show lateral range of measurement for the dipole-dipole arrays serves to indicate the actual earth which has been sampled. This is not adequately shown when the survey line location alone is plotted.

An envelope encloses sections of the plan map (Figure 5.1) to indicate the scope of array sampling along the route of the survey line. The distance from the line to the edge of the envelope is an estimate of the extent of effective search for the array dimensions used, a value based on the depth of investigation characteristic (D.I.C.) (Roy and Apparao, 1971) of the maximum array dimension used, as modified for pseudosection use by Edwards (1977), who calls it effective penetration, $Z_e$. In essence, any strongly anomalous conditions at the edge of or within the envelope, to either side or to corresponding depth below, will be apparent in the pseudosection data (provided other local effects do not obscure the results). Thus, where an anomaly is represented by a bar plotted along the line, the observer can use the envelope in conjunction with the pseudosection to identify and evaluate possible geologic or topographic explanations for the anomaly.

In broader terms, the envelope plot serves as an immediate visual catalog of resistivity data coverage (as opposed to resistivity line location). Where no anomaly exists and no indicators of topographic or stratigraphic masking or distortion are present, the terrain enclosed in the envelope can be considered "explored" to the limits of the $Z_e$ definition of the envelope boundary. Where an anomaly exists, and no firm indication of anomaly source location can be determined (a shallow anomaly at distance "d" to one side may, in pseudosection data, look the same as an anomaly at depth "d" directly under the line) the combination of data envelope and anomaly bar allows the appropriate fitting of follow-up parallel or perpendicular lines to the area terrain. The trial plotting of any proposed detail line and its search envelope provides an opportunity to test the potential effectiveness of the proposed line in clarifying the anomaly source position.

## 5.1 Lower valley coverage

Much of the lower valley area around the volcanic complex has been sampled at least once. Notable areas of limited coverage are the zone west of the south reservoir anomaly, which is of interest due to the implications of drilling (M8-79D) and modelling of Line K data, and the area surrounding the confluence of Meager Creek and the Lillooet River, where numerous indications of local anomalous conditions have not been linked up.

The valley areas south and southwest of the south reservoir anomaly are not fully explored to date, and may contain the source of geothermal fluids observed in the South Fork anomaly system.

## 5.2 Alpine area coverage

The development of multiple pole-pole survey in 1977-1978 provided coverage of the northerly extension of the south reservoir anomaly, and sampled the breccia pipe area extensively. It also provided coverage of both sides of the Lillooet River valley for much of the distance between Plinth Peak and Pebble Creek, identifying a lower resistivity unit on the south side, and finding no anomalies on the north side.

Much of the alpine area remains untested. Three factors make the obtaining of results in the central complex area difficult:

a. Ice covers the greater protion of the alpine area, requiring special precautions for crew movement, and instruments capable of operating between bare patches, or through the ice.

b. Many areas are near-vertical, or are unstable and in frequent landslide or icefall, limiting crew access.

c. Dependence on helicopters for movements including access and return to camp on a daily basis increases operating costs and uncertainties due to weather variability.

# 6.0 INTERPRETATION OF MAJOR ANOMALY SYSTEMS

## 6.1 South Reservoir resistivity anomaly

The focus of interest in the resistivity description of the south reservoir anomaly has been sharpened by recent two-dimensional modelling of resistivity results. These results indicate a zone of low resistivity of about .5 km width lying east from No Good Creek, and oriented north into the complex. In both models, the structure apparently extends to depth beyond the range of interpretation, or a depth of 1500 metres below surface. The west half of the south reservoir anomaly is underlain by 1000 ohm-metre materials, probably relatively intact basement rocks.

These models (Figures 6.1 and 6.2) are a first interpretation based on the resistivity data alone, without presently available seismic data, drill logs, and other data. The model of the south reservoir structure could be significantly enhanced by further computer-assisted work using these data, and extending the modelling process to include Line D data in the same area, and using the a=1000 feet data to further pinpoint the shallow effects of the brine-soaked overburden.

Ward (appendix B) suggests that the south reservoir anomaly is part of a major regional structure which extends north and south of the Meager complex, and passes through in line with the south reservoir anomaly, most of the south-north eruptive centers trend, and through the north anomaly at line L. Extending this computer analysis would test the proposal of extensions of the present zone both north and south from the bench area.

It is interesting to note that the highest near-surface non-inverting temperature gradient is located at well M7-79D, located directly over the resistivity zone. The highest absolute temperature in the upper kilometre regime is also located there.

The models provide resistivity evidence of a cause for the isothermal nature of the lower part of well M10-80D: the drill passes through conductive materials for the first 200-250 metres, then enters an area marginal to a 300 ohm-metre block (this boundary between these units is approximate), heading toward 300 and 1000 ohm-metre rock units of probably marginal permeability and high temperature (approximately 160°C) that is probably resulting from very high temperatures in the 50 ohm-metre zone to the west.

Well M13-81D just west of No Good Creek penetrates the west edge of the main 50 ohm-metre zone, and yields a temeperature of 114°C within 600 metres.

All of the section data west of No Good Creek should be verified by additional measurements and modelling to eliminate the dependence on a few readings for the present interpretation. As it stands, the 100 ohm-metre zones are potential drill targets themselves, but require a better data base prior to further evaluation.

Recommendations:

a. Lines D and K should be extended west as far as possible (3 km) to obtain additional data for modelling in the area west of No Good Creek. Such modelling should be undertaken.

b. Existing Lines D and K data should be intensively modelled with the use of all existing hard measurement data from drilling and geophysics, as per the recommendation of S. Ward (appendix B). Mr. C. Mackelprang of UURI Earth Science Laboratory should undertake the modelling using their IP2D forward modelling routine.

c. The results of rotary hole #3 should be input into the interpretation process as soon as temepratures and indications of permeability are available.

## 6.2 North resistivity anomaly, north central anomaly area

The north resistivity anomaly was first identified on Line L from reconnaissance resistivity data. A one-dimensional inversion of anomaly data confirmed the manually derived model shown in figure 6.3. The adjacent test well L1-78D encountered a basal till underlying the rhyodacite flow unit at a point coincident with the interpreted top of the conductive resistivity unit. This implies that the main conductive unit and possibly the source of hot fluids influencing test well L1-78D lies within the basement rock complex, and is overlain with a more resistive portion of flow unit. The basement zone is about 1 km wide by this interpretation, and corresponds with the general north-south major structure model of Ward (appendix B).

Whatever is occurring to the south of this area, the anomaly L-1 itself is of sufficient interest to warrant a more detailed computer-assisted evaluation of the structure. The former inversion was a parametric method constrained to a two-layer case in one dimension, and represents a very minimal study by 1981 standards. The 2-D forward model would help to establish if it is a linear structure, if it might be of a form compatible with the Ward model, and if it is of similar character to the apparent linear structure on lines N and R on Polychrome Ridge to the west.

Very little else can be said about the north anomaly from the amount of data presently in hand.

Recommendations:

a. Model the data associated with the north anomaly itself, starting with line L anomaly L-1, and extending to the the data describing anomalies O-1, V-1, and N-1 (Figure 5.1). Use the UURI IP2D routine.
b. Model anomalies N-4 and R-1 to test for a linear conductor possibly marking an outflow from a system upslope. UURI IP2D.

c. Model anomalies Q-1 and Q-2 to determine their characteristics in general, and to determine if Q-2 marks the northward progression of Ward's north-south structural control model (appendix B).
d. Extend resistivity coverage south and west of present coverage.

### 6.3 South Fork anomaly system

This system loosely contains all of the known geothermal manifestations on the southeast side of Meager Creek, and up into the South Fork valley area. Of these manifestations (Figure 5.1), the Meager Creek Hot Springs and the warm seeps along the Meager Creek east bank may relate to the south reservoir outflow, but may also be partially or completely originated in the area southeast and south of the Meager Creek valley.

There are sufficient indicators in the South Fork valley (saline surface waters, saline brine in well M12-80D, strong resistivity anomalies up the hydrologic gradient from the south reservoir plume) to indicate a separate point of origin for the geothermal waters mapped throughout the area.

Ward's north-south structure model, with some faint support on Line T immediately south of the south reservoir, would cross the headwaters of the South Fork in a position suitable to supply saline waters to the full length of the South Fork creek valley. Such waters, originating from some geothermal system but cooled in travelling along this major structural conduit, could mix with hot south reservoir outflow waters at their junction at Meager Creek, providing the warm seeps and mixed, partially reequilibrated waters at Meager Creek Hot Springs.

Depending on controlling structures in the area, this explanation could cover all observed manifestations in the South Fork Anomaly System. The interpreted shallow anomaly S-2 high above the Hot Springs on Hot Springs Creek indicates lateral flow of saline waters eastward downhill in the area. The tentative explanation for the contorted character of the anomaly is a set of orthogonally connected fractures in the area. Such a fracture set could be loacted to fit the model of a single source of saline fluids, but there remains the likelihood that if saline fluids are indeed resposnible for the S-2 anomaly and the strong downhole resistivity variation in M14-81D, the source must be uphill to the east. This constitutes another possible source for much of the northern South Fork Anomaly System fluids, a source which can not exclude the probability of the South Fork headwaters inflow as well. The data available for interpretation near Hot Springs Creek (anomaly S-2) are inadequate. A simple detail line at smaller spacings would help to resolve the questions about an eastern source of brine.

Recommendations:

a. Extend Line S data coverage up to 6 km west, crossing the South Fork headwaters area and the southward projection of Ward's north-south model.
b. Operate an a=100 metres detail line across Hot Springs Creek on Line S to resolve the inetrpretation of S-2 and the eastern brine source possibility.
c. Complete the shallow readings of anomaly T-1 so that this line can be modelled to determine the stratification of lateral brine flow and/or the presence of a structure which may be controlling local fluid movement.
d. Plan to model T-1 as above, and the results (if any) of the line S extension across the north-south projection.

## 7.0 COMMENTS ON AREAS OF INTEREST IN FIGURE 5.1

The point-form discussion of the areas identified by letters A through Q on Figure 5.1 is intended as a basis for further discussion toward planning the next increments of exploration. Principally resistivity observations are made, but other observations may be noted as well. The suggestions for resistivity work represent possible components of an exploration plan which would require input from geologists and geochemists, and whose final form may or may not include resistivity survey.

## Area A

### Coverage to Date

Area A has been very superficially tested with resistivity to date.

- 8 to 9 Schlumberger spot measurements (1981).
- one corridor of multiple pole-pole data at east edge (1978).
- a few dipole-dipole measurements on the ends of lines D and K (1974,1975).

### Reasons for Interest

- immediately adjacent to the main South Reservoir zone.
- both 2-D models of line K data suggest conductive zones within area A, both as extensions to the South Reservoir in zone and as a possible second zone west of Boundary Creek.
- the limited pole-pole coverage suggest increased conductivity at depth on the upper slopes of eastern area A.
- the five Schlumberger spot measurements between Boundary Creek and No Good Creek support increased conductivity at depth.

### Possible Models

Since the location of the geothermal system supplying heat and brine to the South Reservoir zone has not been identified, area A lying immediately adjacent to the west is of more than passing interest. None of the resistivity data obtained to date excludes the possibility of a large geothermal system underlying the zone. There remains physical room for a large geothermal system centred on or northeast of the Devastation Creek valley. The moderately high temperature gradient (125$^{o}$C/km) may result from lateral heat transfer from the main zone of the South Reservoir, but could equally represent lateral flow from the north or west of area A.

Area B

Coverage to Date

Area B comprises the higher altitude ground to the east and southeast of dipole-dipole line S which follows the Meager and South Fork valleys. No resistivity data has been obtained in Area B.

Reasons for Interest

- reasonably close to the South Reservoir activity, and lying on the strike of a major northwest lineament.
- Area B abuts a long string of geothermal manifestations labelled as the South Fork anomaly system (Figure ).
  - Meager Creek Hot Springs waters are of undefined origin and could contain a component originating from area B directly upslope to the southeast.
  - a resistivity anomaly on line S at Hot Springs Creek is interpreted as indicating lateral near-surface flow of conductive waters from within area B downhill towards Meager Creek.
  - the warm seeps observed along the bank of Meager Creek between the Meager Creek Hot Springs and the South Fork issue from the southeast side of the creek, and could contain thermal water from area B.
  - resistivity anomalies in the South Fork area (on lines C, E, S. T, and ELA) could be caused by saline outflow from area B.
  - saline brine under artesian head was observed in test well M12-80D located on a lower slope of area B.
  - a saline surface run-off has been observed on a lower slope of area B, south of test well M12-80D.

## Possible Models

The geology of area B is at present only superficially known. Hydrologic principles suggest that saline waters observed in the southern part of the South Fork anomaly system do not originate in the South Reservoir area. The salinity of these waters indicates a geothermal origin. The low temperature of the measured waters indicates that they have travelled sufficient distance to have cooled to local ambient temperatures. The source of the saline waters must lie some distance away from the observed anomalies, in either area B or area C, or in the area to the south. A geothermal reservoir lying in the upper slopes of area B could be supplying the conductive fluids which cause the line S anomalies on the lower slopes. Such a model does not conflict with any existing data; indeed the proposition for a northwest striking major lineament through area B provides an ideal transport mechanism for the brine.

## Area C

### Coverage to Date

Area C is bounded by dipole-dipole resistivity survey lines F, T, S, and ELA. Survey lines C and E approach the area, with line C entering the area.

### Reasons for Interest

- area C lies up the hydrologic gradient from consistent and strong resistivity anomalies lying in the South Fork drainage. ( See area B)
- area C contains the intersection of the headwater area of the South Fork and the southward extension of a linear zone proposed to run through the south reservoir area (Ward, 1981).
- saline surface waters have been observed in swampy areas near the headwaters of the South Fork (Openshaw, pers: comm.)

### Possible Models

The geology of area C is at present only superficially known. Hydrologic principles suggest that saline waters observed in the southern part of the South Fork anomaly system do not originate in the South Reservoir area. The salinity of these waters indicates a geothermal origin. The low temperature of the measured waters indicates that they have travelled sufficient distance from a geothermal system to have cooled to local ambient temperatures. The source of the saline waters must lie some distance away from the observed anomalies in either area B or area C, or in the area to the south. A major structural zone, possibly a southern extension of the South Reservoir main zone (Ward, 1981) may be a suitable conduit for the local introduction of saline brine. If such brines are travelling at depth along this permeable structure from the South Reservoir area, then perhaps sufficient distance will have been covered to permit their cooling to the low local ambient temperatures in near-surface area C.

The source of the saline waters observed in area C and in parts of the South Fork anomaly system could originate from structures or systems completely independent of the South Reservoir area. Some manifestation of this structure or system is likely to be identified somewhere in area C.

Area D

Coverage to Date

The area around the confluence of Meager Creek with the Lillooet River has been peripherally sampled repeatedly, not as yet has not undergone a systematic survey. 1977 multiple pole-pole array work centered on the area, and yielded highly ambiguous results which nonetheless contained some reasonable indications of anomalous conductivity in the area.

Reasons for Interest

- Line A (1974) terminates near $D_1$ with indication of strongly anomalous conditions downstream from Pebble Creek.
- Line V (1980) terminates near $D_1$ with indication of anomalous conditions downstream.
- Testing of 1977 pole-pole array indicated extreme near-surface conductivity near $D_3$.
- Soundings S-1 through S-4 (1976) indicate conductive alluvium.
- 1978 pole-pole Lillooet Valley Resistivity Anomaly can be projected through point D at the confluence.
- A lack of apparent sediment conductivity at $D_4$ appears to at least structurally disconnect the area D from the brine systems associated with the Meager Creek Hot Springs.
- Major structures in the Lillooet and Meager Valleys may intersect in the area.
- A volcanic vent has been reported some distance up Pebble Creek.
- The Capricorn Creek watershed drains into area D. This watershed drains a large area involving at least three eruptive centers at or near Pylon Peak, Capricorn Mountain and Meager Mountain, providing an opportunity to supply outflow brine to area D.
- Drainage from the north slopes of Mount Meager and the area toward Plinth Peak enters area D at surface at the point where the

anomalies A-2 and V-4 begin, and where conductive sediments are noted.

## Possible Models

The amount of unconnected data yields a large number of speculative models, none of which can be preferred on the basis of present data. Access to the center of the south-north eruptive center trend via Capricorn Creek is perhaps a useable way to obtain mid-complex data, operating a carefully planned resistivity section up the Creek and across the eruptive trend to the west along the south edges of Capricorn Mountain and Mount Job. If the regional north-south suture model of Ward is providing some local control of fluid circulation or displacement, then such a traverse would be possibly diagnostic.

Substantial support information can be had much more easily, however, by completing resistivity measurement coverage of the area marked by $D_1$ through $D_4$, using the established network of existing roads. Resistivity measurements up Capricorn and surface water conductivity testing in the Capricorn watershed and on the slopes above and below the Lillooet Valley Resistivity Anomaly would help to indicate the possibility of a geothermal system associated with Meager Mountain being responsible for most of the Area D anomalies.

The limited present data also carries a caution in developing models at this stage. For example, the bulk of the conductive media in Area D sediments could be settled fines and clay particles deposited from Lillooet River and Meager Creek waters over a long period. The map indicates that the anomalous area coincides with the first major decline in stream gradient (except for the area above Salal where conductive, settled sediments also occur) for both watercourses. The low cost of completing valley bottom and lower slope measurements indicates that the data set should be completed before major models are seriously considered.

## Area E

### Survey Coverage

Area E is bounded on the north by dipole-dipole survey coverage. Line M along Job Creek extends south into the area. At the east edge of the area, the Lillooet Valley Resistivity Anomaly approaches the area.

### Reasons for Interest

- The resistivity anomalies of Lines M and N are open into area E.
- The 103°C temperature and high gradient in L1-78D may relate to a system in area E (or F).
- There is a strong and unresolved SP response across lower area E.
- The Lillooet Valley Resistivity Anomaly approaches the area and has not been cut off.
- The area may hold the site of the most recent pyroclastic eruption and in known to contain the vent from which the recent dacite flow issued into the Lillooet Valley.
- Anomalies A-3 and V-3 and nearby Pebble Creek Hot Springs lie to the northeast of the area.

### Possible Models

There are numerous possible models for this area, particularly since it sits on the north end of the northerly trend of eruptive centers and contains very recent vent sites. To the present considerations for the area, the resistivity data indicates that further exploration should keep the Ward north-south structure model, with its passage through anomaly L-1, in mind.

The cause of the SP anomaly reported from the fall-line leading down to drillsite L1-78D is not understood at present. It could indicate major fluid upwelling in the area of the letter E on the map, or it could be caused by vigorous drainage of meteoric waters within a permeable layer in the flow sequence on the slope.

## Area F

### Survey Coverage

Area F is bounded on the north by dipole-dipole survey coverage. Dipole-dipole line X bisects the area. Area F is contiguous with areas E and G.

### Reasons for Interest

- Resistivity anomalies on all bounding dipole-dipole lines.
- Visible surface hydrothermal alteration in the area,
- With resistivity anomalies apparently cut off to the north, exploration south into the volcanics is indicated.

### Possible Models

There are no specific resistivity-based models to be proposed for testing at this time: Exploration planning for this area is underway at present.

Area G

Survey Coverage

Area G is bounded to the north by Lines N and R. No other resistivity survey has been undertaken in area G.

Reasons for interest

- The anomalies on Line N and R suggest a north-south trending structure.

- Depending on the demonstrated strike of the anomalous structure, area G may demonstrate connection of the structure with area F.

Possible Models

This anomaly could indicate an outflow from a geothermal system to the south contained within a north-south fracture zone. Little is known about area to date.

Area H

Survey Coverage

Area H is bounded to the south by Lines N and R. No other resistivity survey has been undertaken in the area.

Reasons for interest

- The anomalous structure identified on Line N and R to the south. These may extend north to the Area H.

- There is no evidence to date that sediments in Area H will mask or otherwise interfere with survey measurements.

Possible Models

The northwest resistivity anomaly may extend as a structure into and/or across the Lillooet Valley. Investigation would depend on assessment of prior work in area G.

## Area J

### Survey coverage

There is no previous survey work in area J. The area lies north of the anomaly on lines N and R, and west of the anomaly on line Q at the west edge of area K.

### Reasons for interest

- If the structure indicated on Line N and R south extends north, survey in Area J may be effective in mapping its continuation.
- The anomaly mapped on the western end of Line Q may extend into Area J.

### Possible models

The area may relate to areas H and K.

Area K

Survey Coverage

Line Q (1979) runs along the south side of area K.

Reasons for Interest

- Area K may contain evidence of the continuation of Ward's (appendix B) north-south major structure (anomaly Q-2)
- Anomaly Q-1 yields a 1-D inversion interpretation indicating extreme conductivity in a thin layer under a probable flow unit.

Possible Models

This is a case of a very limited amount of data providing an interpreted section of large potential ambiguity, both in reliability and exclusivity of the inversion result itself, and in the range of possible models for the interpreted result. The most acceptable model is that of a conductive clay basal till under a flow unit of moderate resistivity, over a basement of high resistivity. Beacuse of the position of the anomaly on the gneral trend of north-south eruptive centers, it is appropriate to also consider a thermal cause for the till conductivity, and to speculate quickly on a vapour-dominated system of resistive cap, conductive condensate layer and resistive hot/dry rock basement.

Such speculation serves best to illustrate the lack of sufficient data in the area on which to eliminate any of this extreme range of models.

Area L

Survey Coverage

Area L is bounded to the south by Line Q.

Reasons for interest

- A moderate anomaly on Line Q (Q-3) is undefined to the north.

Possible Models

Area L lies between the north resistivity anomaly and further at least one center of hydrothermal alteration at the headwaters of Salal Creek, and may lie on the contact between the Fall Creek stock and the local basement rocks. It is also generally in the path of the south-north eruptive center trend. The anomaly Q-3 may be sampling a portion of a more conductive manifestation north or south of Line Q.

Area M

Survey Coverage

Area M is bounded to the south by Line V.

Reasons for interest

- Anomaly V-2 is open to the northwest toward Area M.

Possible Models

Anomaly V-2 could represent outflow from a system located to the north or northwest.

## Area P

### Survey Coverage

Area P covers much of the central alpine area of the complex, where almost no measurements have been obtained to date.

### Reason for Interest

This area is of obvious exploration interest due to the number of volcanic vents within it. The lack of comprehensive measurement coverage to date is caused by the difficulty in operating in this type of terrain, from both an equipment and personnel standpoint. The difficulty in conducting exploration in this area, combined with the probable difficulty in test drilling and exploiting a resource located therein, tends to allow the area to be set aside while other more accessible and reliably exploitable areas are explored.

The deferred status, if it exists, should be reviewed periodically to assure that the conditions supporting it have not changed to allow a cost-effective evaluation at some future date. The changes might occur in exploration technology, exploitation technology, or both.

The largely untested area P contains sufficient area to locate 10 to 12 geothermal systems of 9 $km^2$ minimum size.

Area Q

Area Q is discussed in 6.1 of this report, and in other reports on the Meager Creek geothermal area. Area Q contains the south reservoir resistivity anomaly.

## 8.0 COMPUTER-ASSISTED DATA INTERPRETATION

A review of available computer-assisted data interpretation routines was undertaken. A separate report on this subject is in preparation at present, the completion of which is dependent upon the results of three different areas of investigation presently under way.

### 8.1 Two-dimensional forward modelling program

The application of an advanced two-dimensional forward modelling routine to Meager Creek data and to Mt. Cayley data from the 1981 reconnaissance propgram has provided some initial results which suggest that the method may be useful in the evaluation of drill sites for initial testing of anomalies. Two of the model results are shown in figures 8.1 and 8.2, in which Line K data from the south reservoir area have been used. These are best fits on a first attempt using the IP2D routine of the Earth Sciences Laboratory of the University of Utah Research Institute. Mr. Claron Mackelprang was the program operator. The models show a zone of low (50 ohm-metres) resistivity at the west side of the main anomaly, extending to a depth in excess of the lower limit of model resolution (greater than 1500 m). The highest temperature and steepest gradient, those of test well M7-79D, were obtained directly over this unit. The lapse of initial steep gradients in test well M10-80D into an isothermal state may be explained in this model by the large block of 1000 ohm-metre rock directly below M10. The test well data obtained in the south reservoir support this model substantially. At time of writing, rotary test well MC3 has been targeted to penetrate vertically just east of the 50 ohm-metre zone, turning west-northwest at depth to test the 50 ohm-metre zone at depth. It is anticipated that the 50 ohm-metre zone will provide better permeability than the rock units lying further east.

These models were generated from the a = 610 m (2000 ft) data only, shown in figures 3.6 and 3.7. No further work is in progress on these data at present; Ward (appendix B) recommends further work be done on south reservoir area modelling using both Lines K and D data and expanding to utilize the available seismic, test-well and shallow Schlumberger sounding data over and near the south reservoir. Such information could provide significant information for planning further testing of the area. It will at least define the reliability of the present general model, and test the 50 ohm-metre zone for sensitivity to single data point variables.

## 8.2 One-dimensional inverse modelling

Work has been going on for several years on the refinement of a non-parametric one-dimensional inversion routine by Dr. Doug Oldenburg of the University of British Columbia. At this time, the routine is being tested on Schlumberger sounding results from the south reservoir area and from a geothermal program in the Anahim volcanic belt in central B.C. (Geological Survey of Canada, Energy, Mines and Resources Canada). This program provides a continuous interpreted resistivity curve for any electrode array configuration, for an assumed one-dimensional (layered) model. It is seen as providing the first useful tool for evaluating the deeper aspects of the 1978 pole-pole survey data, including the anomalous area above the south reservoir where conducyive volcanics overlie crystalline units of unknown resistivity characteristics. The routine could also provide for evaluation of two- or three-point Schlumberger data on a rough scale.

This routine may be available for use by late 1982.

## 8.3 Availability of routines for in-house operation

The availability of computer routines for outright purchase, operation under licence, or use as a consultant-operated hourly-rate service is under study. Most routines benefit from the experience and understanding accumulated by their creators or present operators, and the obtaining of physical software may not constitute a direct benefit to the exploration program. On the other hand, the development of a degree of competence with the routines by local personnel assures that the full familiarity with the exploration situation is brought to bear on the program operation. Most available routines can be accessed and used on a time-share basis for a yearly fee or a per-use fee, using a local terminal. Substantial savings in cost and time, and in particular in flexibility, can be obtained by implementing programs on owned computer facilities, where access may be easier, and the CPU costs more favourable. The leading modelling technique, the IP2D routine, is written in PRIME Fortran and is available on licence terms for local implementation.

Respectfully submitted,

Greg A. Shore

Michael G. Schlax

April 27, 1982

Appendix A

References cited:

Edwards, L.S., 1977, A modified pseudosection for resistivity and I.P.: Geophysics; Vol. 42, No. 5, p. 1020-1036.

Roy, A., and Apparao, A., 1971, Depth of investigation in direct current methods: Geophysics, Vol. 36, p. 943-959.

APPENDIX B

# Report on Analysis of Dipole-Dipole Resistivity Data, Meager Creek, British Columbia

for

Premier Geophysics Inc.

by

Stanley H. Ward

4.1.1

**STANLEY H. WARD**
*Geophysical Engineer*

729 Hilltop Rd.
Salt Lake City, Utah 84103
May 7, 1981

Mr. Greg Shore
President
Premier Geophysics Inc.
134 Abbott Street
Vancouver, B.C.

Dear Greg,

Herewith my report on analysis and interpretation of the dipole-dipole resistivity data at Meager Creek.

Please telephone me should you require clarification on any aspect of the report.

Yours sincerely,

Stan

Stanley H. Ward

# Report on Analysis of Dipole-Dipole Resistivity Data
# Meager Creek, British Columbia
# for
# Premier Geophysics Inc.

## 1.0 Introduction

### 1.1 The Assignment and Data Base

At the request of Greg A. Shore, President, Premier Geophysics Inc., a one day analysis was made (May 6, 1981) of the dipole-dipole resistivity data accumulated at Meager Creek during the interval 1974-80. The results of three Schlumberger soundings were taken into account in interpreting the dipole-dipole data, but the Schlumberger data was not seperately interpreted in a rigorous manner. No study was made of available pole-pole resistivity data since such would have been beyond the scope of the request for consultation.

In interpreting the dipole-dipole resistivity data I benefitted from extensive discussions with Greg A. Shore and from brief discussions with Brian Fairbank of Nevin Sadlier-Brown Goodbrand Ltd. Account was taken of current knowledge of topography, geology, drill hole information, brine chemistry, tectonic history, ages of extrusive rocks, and preliminary quantitative interpretation of a single profile of dipole-dipole data (interpretation of Line K by Claron Makelprang of the Earth Science Laboratory of the University of Utah Research Institute). My previous knowledge of the Meager Creek geothermal prospect was acquired through discussions with personnel of Nevin Sadlier-Brown Goodbrand Ltd., through a one day visit to the property, courtesy of the latter firm, and through study of the literature referenced herein.

1.2 Presentation of Analysis

A plan map at a scale of 1:20,000 to be overlayed on the geologic map (GSC Open File 603) of Peter B. Read, is used herein to present the significant resistivity lows found in the analysis. The correlation between geology, geophysics, and thermal springs is thereby afforded.

2.0 Pertinent Geologic Features

2.1 Regional and Local Trends of Eruptive Centres

Figure 1 (Lewis and Souther, 1978) illustrates the NNW trend of the Garibaldi belt of Quaternary volcanism. Locally, between Meager Creek and the Lillooet River and possibly beyond to the Bridge River, the trend lies almost due north as shown in Figure 2 (from Roddick and Woodsworth, 1975). These authors state that "This belt thus appears to be the locus of a major fracture system that persisted from a least Miocene to Recent time." Potassium-Argon dates of extrusives are shown to the right of this figure. Figure 3 (from Read, 1978) shows the locations and ages of volcanic vents between Meager Creek and the Lillooet River. The axis of the vent system and the eastern and western bounds of it are superposed on this latter figure.

2.2 Mapped Local Faults

Souther (1980), in reporting on the Central Garibaldi Belt, notes that "The only basement structures that appear to be related to the volcanic belt are north-northwesterly trending, gouge-filled fractures." Read (1978) observes that "Springs and volcanic vents trend northerly and are spatially associated, particularly if the estimated position to the subcrop of Meager hot springs is considered." ...."Fracturing during rhyodacite volcanism in these vent areas probably produced the necessary premeability to depth in the basement, which permits deep circulation of the spring waters in this area of abnormally high

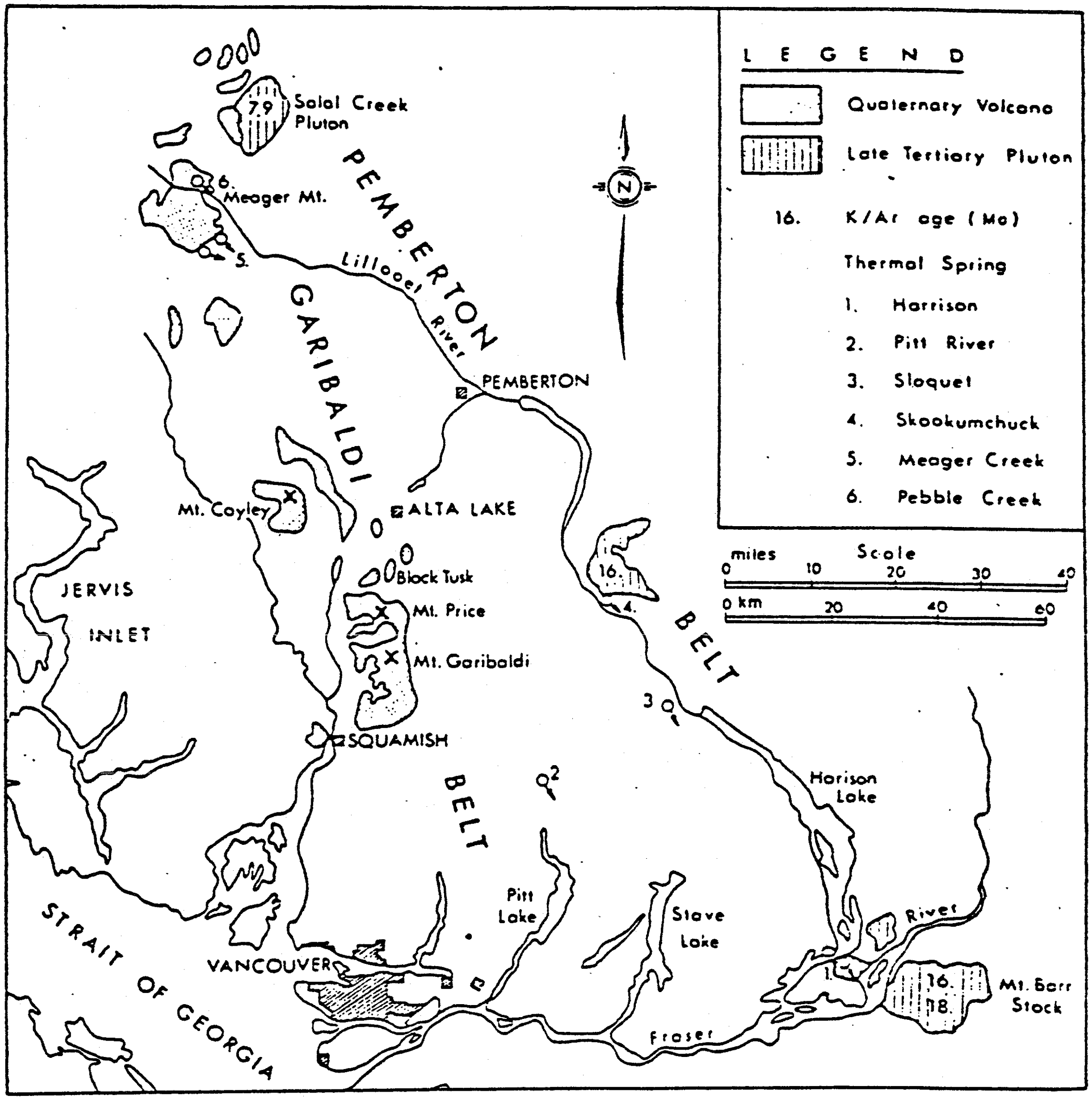



FIG. 1 The Pemberton belt of late Tertiary plutons and the Garibaldi belt of Quaternary volcanoes (from Lewis and Souther 1978).

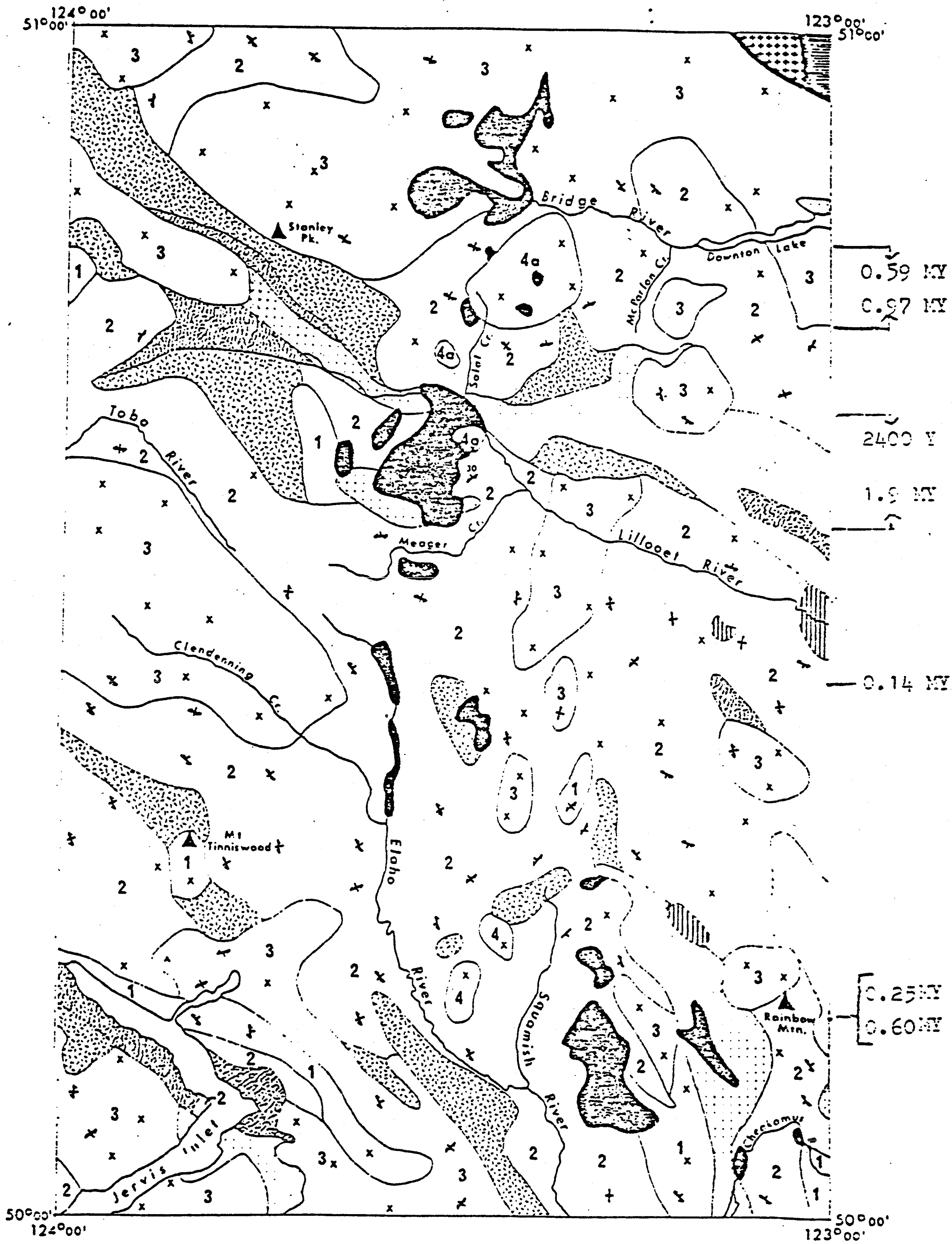



Fig. 2 Distribution of Quaternary rocks (dark areas) and their age distributions. (After Roddick and Woodsworth (1975).

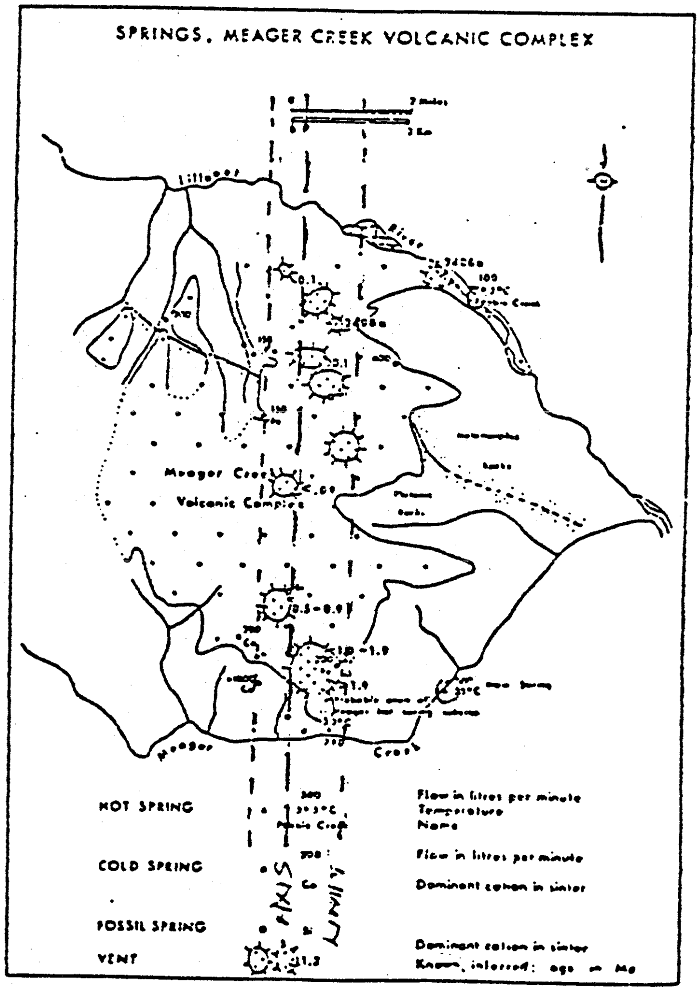



Fig. 7. Meager Creek volcanic vents
(after Read, 1978)

2.2 Mapped Local Faults (cont'd)

heat flow." Fairbank (personal communication) observes a dominant 130° fracture set dipping 60° SW and a secondary 20° fracture set dipping vertically. He observes some faults parallel to these trends. North-South fractures are strong and consistent. Fractures radial to the Meager Creek volcanic complex are not observed. Meager Creek appears to lie along an East-West fault dipping 45° to the north.

2.3 The Conceptual Model Implied by Local Volcanic and Structural Trends

The heat source would appear to be a linear NS trend of intrusives associated with the volcanic vents of Figure 3. Pulses of magma evidently introduced heat and fracturing along this NS trend. Where the topography has been deeply disected, as at Meager Creek and the east-west segment of the Lillooet River to the north, access to high temperature regimes ($\sim$ 200°C) is afforded. The south fork of Meager Creek may afford the same deep access, although the potential source of heat south of Meager Creek is currently unknown. Barr Creek and Hot Spring Creek may also afford access to warm or hot fluids. Hot springs vent along fractures associated with the deeply disecting valleys but the waters so vented are not intimately connected with the deep high temperature convective hydrothermal system (Hammerstrom and Brown, 1977). The drilling target would appear to be a fracture or preferably an intersection of fractures, of any orientation, at a depth sufficient to penetrate the deep high temperature part of this convective hydrothermal system. The system is conceptually bounded on the east and west by the dotted lines shown in Figure 3.

2.4 The Dipping Sheet Model (South Reservoir) of Nevin Sadlier-Brown Goodbrand Ltd.

Quoting Nevin et al (1978), "The South or Meager Creek Reservoir as it is presently known, is a tabular body which

2.4 The Dipping Sheet Model (South Reservoir) of Nevin Sadlier-Brown Goodbrand Ltd. (cont'd)

occupies about 5 sq. km. and dips to the north under the volcanics edifice. The leading hypothesis is that it consists of a slow discharge-plume from a presumably permeable feeder pipe for the southermost volcanics...."

2.5 Sources of Low Resistivity near a Convective Hydrothermal System

Brine satruated alluvium will exhibit resistivities in the 1 to 10 ohm metre range. Brines and associated clay alteration of feldspars will lower the resistivity in the close vicinity of a fracture in rock. The otherwise impermeable quartz diorite basement at Meager Creek will only possess low resistivity where highly fractured; the resistivities of such reservoir rocks ought to lie in the range 10 to 100 ohm metres.

3.0 Depth of Exploration and the "Lateral Range" of Dipole-Dipole Resistivity Surveys

The depth of exploration, d, of dipole-dipole resistivity surveys is conventionally given as

$$d = 0.2\ (n + 2)\ a$$

where n is the spacing (n = 1,2,3,4,5, and 6) and a is the dipole length. Thus for n = 6 and a = 1000 ft., it is 1200 ft. Recent work suggests that this formula is slightly pessimistic and that the simpler formula

$$d = 2a \text{ to } 3a \ (\text{for } n = 6)$$

is more appropriate. This would increase the depth of exploration for 1000 ft., dipoles to 2000 ft to 3000 ft.

The lateral range of the method is the same, numerically, as the depth of exploration. Hence resistivity contrasts within about 2000 ft. on either side of a 1000 ft. dipole-dipole traverse line will affect the data and, unless great care is taken, may be interpreted to lie vertically below the traverse line.

## 4.0 Data Interpretation

### 4.1 Procedures

The pseudosections of apparent resistivity obtained with the dipole-dipole survey method were interpreted qualitatively with due regard for the factors entering the discussions of 2.5 and 3.0 above. Zones of low resistivity which are believed to be of significance to delineating the convective hydrothermal system have been marked of Figure 4, which is an overlay for Peter B. Read's 1:20,000 geologic map of Open File 603, Geological Survey of Canada. For Line K, a preliminary quantitative interpretation was available as noted earlier. The zones of anomalously low resistivity have been correlated with geology and topography for purposes of discussion.

### 4.2 South Reservoir

The resistivity low in the vicinity of the so-called South Reservoir is defined by resistivity data on lines D, K, and T, as follows:

#### 4.2.1 Line D

There is an abrupt increase in resistivity west of 110W on Line D, approximately at the location of No Good Creek. East of 110W on this line, the resistivity are low to 10E, but from about 90W to 10E they are underlain by much higher resistivities. No quantitative interpretation of the data for this line has yet been made. The low resistivities at shallow depths from about 90W eastward may be attributed either to conductive glacial clay or to brine saturated valley fill. The latter explanation is preferred because of the abrupt increase in resistivity west of 110W, ie: No Good Creek, and because warm and hot springs occur to the east but not to the west of No Good Creek. No attempt has been made to define the eastern boundary of the deep conductive zone, believed to exist between 110W and 90W, because no quantitative interpretation of this data has been made.

4.2.2. Line K

The resistivity pseudosection for Line K is similar to that for Line D, with the exception of a pronounced resistivity low associated with Meager Creek at 65E. While this latter feature may result from local hydrothermal convection, it is more likely results from brine filled alluvium wherein the brine originated upstream, ie: near No Good Creek. More resistivity work is required to verify this preferred interpretation.

A preliminary quantitative interpretation of Line K has indicated a deep conductive zone, ie: well below valley fill, of 50 ohm metre material occurring between 40W and 60W. The western boundary of this zone coincides approximately with No Good Creek.

4.2.3. Line T

A very weak and surficial low resistivity anomaly occurs on Line T as an extension of the anomaly found on lines D and K. The significance of the anomaly is unknown.

4.2.4. Recommendations

1) The effects of overburden seem to be adequately accounted for in modelling the data from Line K, but there is a need to remodel the data using for control the following:

a) the latest geologic plan map,
b) the available geological sections for AA', BB', CC', and DD',
c) the available seismic data depicting the bedrock profile beneath Meager Creek,
d) the inversely interpreted Schlumberger soundings when extended to AB/2 of 2 km.,
e) sensitivity test involving variation of width, depth, extent, and resistivity of the 50 ohm metre block of low resistivity material in the bedrock.

2) Line D should be modelled with the same attention to detail recommended for Line K above.

3) If a deep production test well is to be drilled at an early date, then its most logical location would

be within 200m east to west of gradient hole M7, with the western part of this zone preferred. However, the resistivity interpretation noted above should be completed and two shallow (600m) gradient holes should be drilled, 200m on either side of gradient hole M7, prior to spudding the production test well. Local vertical and lateral temperature gradients are expected to be markedly influenced by convecting fractures so that much attention is required to optimize the location of the deep production test well.

## 4.3 M12 Area

### 4.3.1. Lines T and S

A resistivity low exists between 10E and 13E on Line T. This may be due to hydrothermal alteration but seems more likely to be due to brine saturated valley sediments since gradient hole M12 intersected a warm brine. Note, however, the resistivity low east of M12 on Line S. There is some question about the validity of some of the data on Line T, due to the loss of shallow resistivity measurements between 9E and 18E.

### 4.3.2. Recommendations

Much more resistivity data is required in order to ascertain the significance of the M12 Area and its relationship to the South Reservoir and the North Anomaly. Accordingly, the following are recommended:

1) Conduct a dipole-dipole traverse up the South fork of Meager Creek in order to determine where the assumed brine satruation of the alluvium ceases. The southermost upwelling of brine may be located by this technique.

2) Conduct a dipole-dipole traverse SSW through M12 between Line S and the South fork of Meager Creek. A possible east-west resistivity low through M12 may be delineated by the data for this traverse and for Line S.

3) Repeat Line T from 3E to Barr Creek in order to fill in the missing data points.

4) Map the area south from M12 in search for a volcanic vent which may be a source of heat.

4.4 The Hot Springs Creek Area

4.4.1. Observations

Some unusual resistivity readings occurred beneath 112S on Line S and a resistivity low occurred beneath 125S on Line S. Both could be attributed to some form of current channeling along orthogonally connected (fracture-controlled?) streambeds.

4.4.2. Recommendations

It is recommended that Line S be repeated with 100m dipoles from 114W to 133W so as to restrict the survey to one streambed.

4.5 South Area, General

4.5.1. Observations

There is considerable uncertainty about the resistivity response of streambeds downstream from Meager Creek Hot Spring. Hence a need arises to conduct Schlumberger soundings at selected locations along Meager Creek.

4.5.2. Recommendations

Conduct five or six carefully selected Schlumberger soundings along Meager Creek (using AB/2 of 2km if possible) in order to assess the importance of variation of brine saturation of valley sediments to the interpretation of Meager Creek. Some dipole-dipole data has gone uninterpreted because of our uncertainty over how to proceed (ie: we are lacking data vital to interpretation).

4.6 North Anomaly

4.6.1. Observations

A continuous zone of low resistivity (of order 150 to 200 ohm metres) has been indicated on Lines L, N, O, Q, and W. This zone is permitted by the data on Line P but the latter line is insufficiently long to provide definitive data. While not of as low resistivity as the South Reservoir anomaly, it is still worthy of attention.

4.6.2. Recommendations

1) Line P should be completed with dipole-dipole resistivity data from its current eastern end to about 83W on Line Q.

2) The west halves of Lines L and Q should be modelled quantitatively.

5.0 Resistivity and the Conceptual Models

1) The resistivity data at the South Reservoir and at the North Anomaly both support the conceptual model presented in 2.3 above.

2) The resistivity data neither confirm nor deny the dipping sheet conceptual model presented in 2.4 above.

3) The resistivity data at the M12 Area and the Hot Spring Creek Area are not easily related to either conceptual model because of a lack of data.

4) Were it appropriate to do so, given all of the constraints of the exploration program at Meager Creek, both the recommended resistivity surveys and interpretation and the trace element geochemistry study proposed elsewhere would be completed prior to spudding the first deep production test well. This recommendation is based on the observation that any conceptual models so far presented to the writer, including those described herein, are tenuous at best.

5) The dipole-dipole resistivity method certainly seems capable of contributing to development of a reasonably firm conceptual model of the Meager Mountain convective hydrothermal system.

Respectfully submitted

Vancouver, B.C.
May 9, 1981

Stanley H. Ward

(original signed by author)

## References

Lewis, T.J., and Souther, J.G., 1978, Meager Mountain, B.C.- A Possible Geothermal Energy Resource, EMR, Earth Physics Branch, Geothermal Series Number 9, Ottawa, Canada, 17p.

Roddick, J.A., and Woodsworth, G.J., 1975, Coast Mountains Project; Pemberton (92J West Half) Map-Area, British Columbia, Geol. Surv. Can., Paper 75-1, Part A, Ottawa, Canada, p.37-40.

Read, P.E., 1978. Meager Creek Geothermal System, British Columbia, Part II. Geology, Trans., Geothermal Resources Council, p.494-497.

Hammerstrom, L.T., and Brown, T.H., 1977, The Geochemistry of Thermal waters from the Mount Meager Hot Springs Area, B.C.: Geol. Surv. of Canada, Open File Report, 34p.

Nevin, A.E., Crandall, J.T., Souther, J.G., and Stauder, J., 1978, Meager Creek Geothermal System, British Columbia, Part I: Exploration and Research Program, Trans., Geothermal Resources Council, p. 491-493.